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HELICOPTER-LOAD TENSION-MEMBER STUDY

John C. Minor, et al

Battelle Columbus Laboratories

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HELICOPTER-LOAD TENSION-MEMBER STUDY

By

J. C. Minor
P. T. Gibson
H. A. Cress

November 1972

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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LONG BEACH, CALIFORNIA

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The objectives of this program were to analyze technology applicable to tension members as it relates to the functional requirements of heavy outsized loads externally suspended from helicopters, and to develop a comprehensive design theory and conceptual designs for tension members which will provide a basis for future detail design, fabrication, and test programs.

The tension-member concepts selected for study included wire rope, wire-rope belt, synthetic rope, synthetic tape, steel tape, roller chain, and jointed links. A weighted-parameter technique was used to begin evaluation of these candidate concepts, followed by an analysis of practical considerations with reference specifically to the 1972, 1975, and 1980 time frames.

The results of this study indicate that, on a long-term basis, synthetic tape and wire-rope belt are the most promising concepts. Only wire rope is acceptable in the short term (1-2 years). Problems that remain to be solved for synthetic tape include high aerodynamic drag and high stored elastic energy. Wire-rope belt is an untried concept for this high-load application. Since high-strength synthetic material is being studied in other programs, wire-rope belt was chosen for the preliminary design phase of this program.

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Corrosion						
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Environmental Damage						
Fatigue Life						
Fleet Angle						
Gimbaling						
Guillotining						
Handling						
Helicopter						
Hoists						
Hoist Drive						
Hoist Hook						
Impact Tolerance						
Inspection						
Jointed Links						
Kink Resistance						
Maintenance						
Minimum Bend Radius						
Non-Destructive Testing (NDT)						
Polyurethane						
Power Conductor						
Roller Chain						
Safety						
Shock Loading						
Shock Unloading						
Stability						
Static Electricity						
Steel Tape						
Stored Energy-Elasticity						
Susceptibility to Gunfire						
Synthetic Fibers						
Synthetic Rope						
Synthetic Tape						
Swivel						
Tension Member						
Thermal Damage						
Torsion						
Vulnerability						
Weighted-Parameter Evaluation						
Wire Rope						
Wire-Rope Belt						

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DEPARTMENT OF THE ARMY
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This report was prepared by Battelle, Long Beach Oc Engineering Research Facility under the terms of Contract DAAJ02-70-C-0064. The tension-member concepts selected for study include wire rope, wire rope belt, synthetic rope, synthetic tape, steel tape, roller chain, and jointed links. A weighted-parameter technique was used to begin evaluation of these candidate concepts, followed by an analysis of practical considerations with reference specifically to the 1972, 1975, and 1980 development time frames.

The objectives of this program were to analyze technology applicable to tension members as it relates to the functional requirements of heavy oursized loads externally suspended from helicopters, and to develop design theory and a conceptual design for tension members applicable to 30-, 40-, and 50-ton helicopter payload capacities.

The conclusions and recommendations contained herein are concurred in by this Directorate. This concurrence does not imply the practicality or endorsement of a particular tension-member concept discussed or recommended in this report. It is believed that in the final selection of a tension member for a specific load handling system, other factors must also be considered.

The technical monitor for this contract was Mr. Richard E. Lane of the Military Operations Technology Division.

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U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
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ABSTRACT

The objectives of this program were to conduct an analysis of technology applicable to tension members as it relates to the functional requirements of heavy outsized loads externally suspended from helicopters, and to develop a comprehensive design theory and conceptual designs for tension members which will provide a basis for future detail design, fabrication, and test programs. The specific tasks undertaken were the following:

(1) Conduct a study of major functions and functional requirements of the tension members of helicopter-hoist systems.

(2) Establish performance objectives, major characteristics, and constraints applicable to tension members with 30-, 40-, and 50-ton payload capacities.

(3) Conduct a review and analysis of applicable technology.

(4) Provide a description or descriptions of basic design approaches for satisfying (2) above.

(5) Conduct an analysis of design approaches to identify and describe a configuration which best satisfies the operational needs according to a measure of effectiveness that will be established during the program.

The tension-member concepts selected for study included wire rope, wire-rope belt, synthetic rope, synthetic tape, steel tape, roller chain and jointed links. A weighted-parameter technique was used to begin evaluation of these candidate concepts, followed by an analysis of practical considerations with reference specifically to the 1972, 1975, and 1980 time frames.

The results of this study indicate that, on a long-term basis, synthetic tape and wire-rope belt are the most promising concepts. Only wire rope is acceptable in the short term (1-2 years). Problems that remain to be solved for synthetic tape include high aerodynamic drag and high stored elastic energy. Wire-rope belt is an untried concept for this high-load application. Since high-strength synthetic material is being studied in other programs, wire-rope belt was chosen for the preliminary design phase of this program.

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LIST OF SYMBOLS

A	cross-sectional area (in.^{2})
DHR	load required for hook recoil to aircraft fuselage (dangerous hook release)(lb)
d_i	drum inside diameter at hub (in.)
d_o	outside diameter of last wrap (in.)
E	elastic modulus (lb/in.^{2})
g	acceleration of gravity (in./sec^2)
k	spring constant (lb/in.)
ℓ	total belt length (in.)
n	number of wraps
P	applied load (lb)
p	pressure on drum (lb/in.^{2})
r	drum radius (in.)
t	thickness of belt (in.)
T	tensile load (lb)
UTS	ultimate tensile strength (lb)
w	belt width (in.)
W_H	hook weight (lb)
wt	weight of tension member (lb)
y	rebound height (in.)
δ	elongation (in.)
ϵ	strain (in./ft)
ρ	weight density (lb/in.^{3})
σ	stress (lb/in.^{2})
σ_{ult}	ultimate tensile stress (lb/in.^{2})

INTRODUCTION

A major functional requirement of U.S. Army helicopters is the transportation of large, heavy loads, frequently external to the helicopter. It has been shown that this function can be best accomplished with subsystems within the aircraft which can raise or lower the load while the aircraft is hovering. The governing component in the design and use of a hoisting system is the tension member itself.

The Battelle study reported herein included as its overall objectives the following:

(1) Conduct a study of major functions and functional requirements of the tension members of helicopter-hoist systems.

(2) Establish performance objectives, major characteristics, and constraints applicable to tension members with 30-, 40-, and 50-ton payload capacities.

(3) Conduct a review and analysis of applicable technology.

(4) Provide a description or descriptions of basic design approaches for satisfying (2) above.

(5) Conduct an analysis of design approaches to identify and describe a configuration which best satisfies the operational needs according to a measure of effectiveness established during the program.

PHASE I
ANALYSIS OF TENSION-MEMBER TECHNOLOGY AND IDENTIFICATION OF CONCEPTS

Phase I of the program covered the first three of the above objectives, and was divided into five tasks:

Task A: Identification of the Major Functional Requirements of the Tension Member

The important parameters relating to the required functions of the external load-carrying system were identified.

Task B: Identification of the Desired Physical Characteristics of the Tension Member

The important parameters relating to the physical characteristics of the tension member were identified and combined with the parameters identified in Task A. The interrelationships between parameters were then investigated and summarized.

Task C: Review of Current Tension-Member Technology

The technology review consisted of numerous personal contacts with helicopter manufacturers and users and tension member manufacturers, and also a thorough literature search of applicable reports, articles, and trade literature.

Task D. Identification of Acceptable Tension-Member Concepts

In all, seven general design concepts were identified and described. These include wire rope, wire-rope belt, steel tape, synthetic rope, synthetic tape, roller chain, and jointed links.

Task E: Development of Techniques for Concept Evaluation

A weighted-parameter evaluation technique was selected for use in judging the various design concepts.

TASKS A AND B: IDENTIFICATION OF MAJOR FUNCTIONAL REQUIREMENTS AND DESIRED PHYSICAL CHARACTERISTICS OF THE TENSION MEMBER

During Phase I the important parameters relating to both Task A, Fundamental Mission Requirements of the Tension Member, and Task B, Desired Characteristics of the Helicopter Tension Member, were identified and put in a 45-x-45-term matrix (Figure 1). The parameter definitions are listed below. The interrelationships among parameters were studied, and important aspects of these interrelationships are summarized in Appendix I.

Definitions of Terms Pertinent to Tasks A and B

(1) Load capacity - The required payload to be carried by the tension member. The load capacities studied in this report are 30 tons (60,000 pounds), 40 tons (80,000 pounds), and 50 tons (100,000 pounds). A gust load factor of 2.5g and a 1.5 factor of safety are applied to both the single and multipoint configuration. In addition, for a multipoint configuration, a cone angle factor of 1.15 is used (representing 30^{o}) and also a center-of-gravity factor of 0.60 (representing a 60%/40% load distribution for fore and aft tension members).

(2) Fatigue life - The number of load cycles experienced by the tension member during its useful life

(3) Shock loading - Loads suddenly applied to the tension member due to aircraft maneuvers or wind gusts

(4) Storage - The storage requirements of the tension member in the hoist system including level-winding, back tension and size of storage drum

(5) Environmental effects - The effect of heat, cold, sand, dust, moisture, corrosives, and sunlight on the strength or useful life of the tension member

(6)	Inspection	- The ease of both external and internal inspection for damage or for compliance with specification
(7)	Safety	- Safe operation with and around the tension member
(8)	Duty cycle	- The acquiring of a load, hoisting up, flying to destination, lowering and releasing load from the tension member
(9)	Useful life	- The length of time a tension member can safely remain in service
(10)	Flight stability	- Tension-member stability under aerodynamic loading
(11)	Load stability	- The stability of the cargo in flight as influenced by the tension member physical characteristics
(12)	Driving power	- The input power required to drive the hoist system while lifting or lowering a load
(13)	Speed	- The hoisting speed of the tension member - 100 feet per minute maximum
(14)	Ease of guillotining	- The ease of severing the tension member at the helicopter
(15)	Cone angle	- The angle measured from the tension member centerline to a line perpendicular to the helicopter horizontal plane - 30 degrees maximum
(16)	Power conductors	- The means for transmitting a signal (electrical, hydraulic, pneumatic, etc.) or power from the helicopter for actuation of the cargo hook or for data acquisition

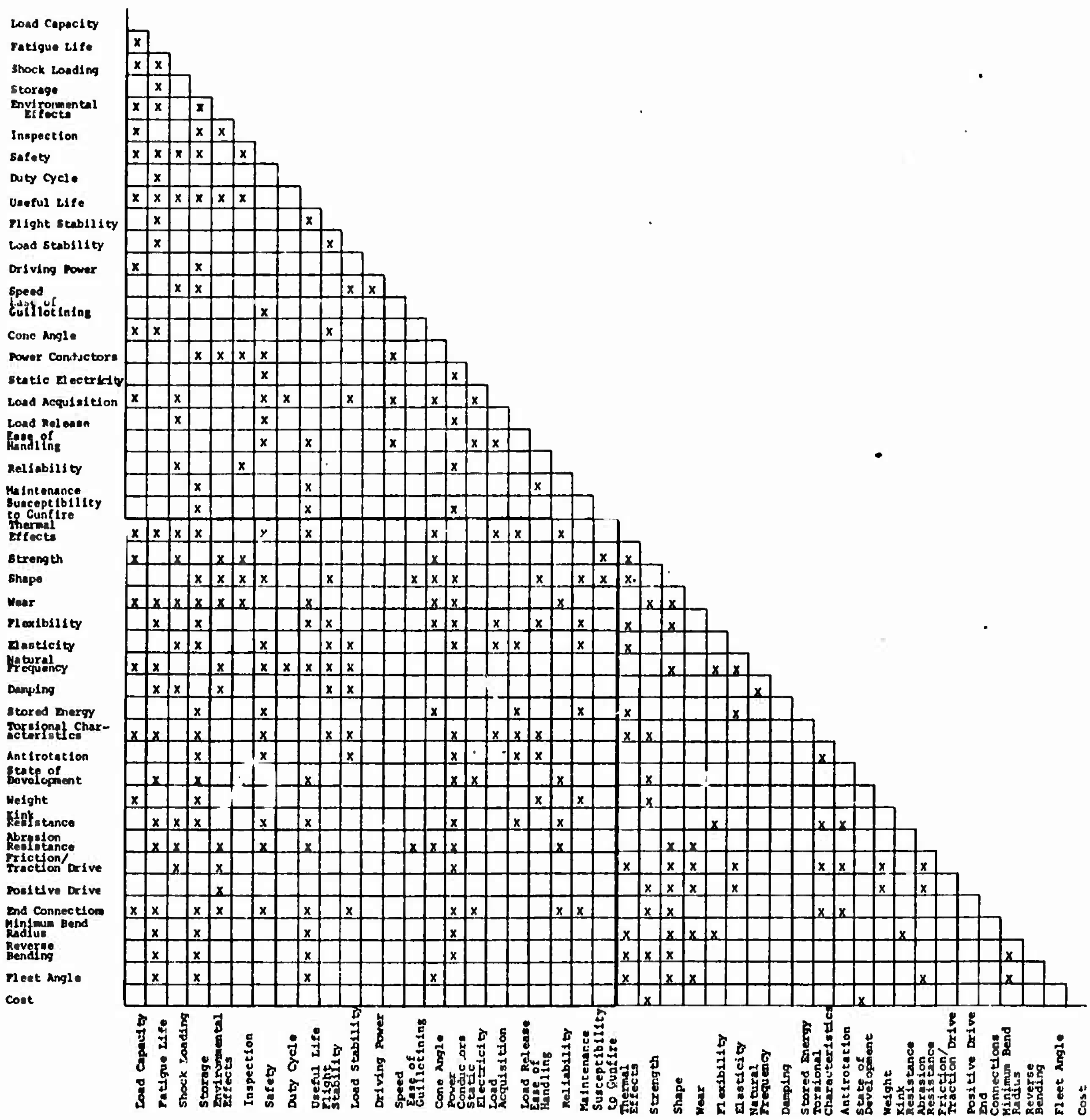


Figure 1. Matrix Relating Key Parameters Pelative to the Functional Requirements and Desired Characteristics for a Heavy Lift Hoist Tension Member.

(17)	Static electricity	- The static electric charge that builds up on a helicopter system during flight
(18)	Load acquisition	- Attaching the cargo and transferring the cargo weight to the tension member
(19)	Load release	- Discharging cargo by normal hook release or by emergency guillotining of the tension member
(20)	Ease of handling	- The ease of manipulating the tension member, either during load acquisition or routine maintenance
(21)	Reliability	- The ability of a tension member to be operated satisfactorily for its desired useful life
(22)	Maintenance	- Amount and convenience of required tension-member maintenance
(23)	Susceptibility to gunfire	- The vulnerability of the tension member and its ability to survive enemy fire while supporting a load
(24)	Thermal effects	- The effects of having one part of a tension member rubbing on another part, creating heat while the member is under tension
(25)	Strength	- The ultimate breaking strength of the tension member
(26)	Shape	- The physical cross-sectional or longitudinal shape of a tension member such as round, square, etc.
(27)	Wear	- The physical reduction in size of the tension-member cross section
(28)	Flexibility	- The ease of bending of the tension member
(29)	Elasticity	- The effective spring rate of the tension member

(30)	Natural frequency	- The frequency at which the tension member will resonate laterally or longitudinally or both
(31)	Damping	- The internal damping that tends to reduce the amplitude of resonant vibrations in the tension member
(32)	Stored energy	- The tensile strain energy in the tension member while supporting a load
(33)	Torsional characteristics	- The behavior of the tension member under torsional loading
(34)	Antirotation	- The physical design characteristic of a tension member which minimizes twist under load
(35)	State of development	- Whether a tension member is still in the R&D stage or is well developed
(36)	Weight	- The mass per unit length of a tension member as well as the total weight of the entire hoist system
(37)	Kink resistance	- The tendency of a tension member to resist damage due to kinking or knotting
(38)	Abrasion resistance	- The ability of the tension member to resist external wear
(39)	Friction or traction drive	- Drive means required to drive the tension member in or out if friction is used for the moving force
(40)	Positive drive	- Drive means excluding friction whereby the driver has positive connection to the tension member
(41)	End connections	- The mechanical and/or electrical terminations of the tension member
(42)	Minimum bend radius	- The smallest radius to which the tension member may be bent while still providing adequate useful life

(43) Reverse bending	-	The bending of a tension member in one direction over a curved surface and then reversing the direction of bending over an adjacent surface
(44) Fleet angle	-	The angle between the centerline of the tension member and the plane perpendicular to the axis of rotation of a sheave or drum
(45) Cost	-	Dollar value for procurement or research and development of a tension member

Tension-Member Design Criteria

The following criteria were used to arrive at the specific physical requirements for the tension-member concepts.

Load Capacities

30 tons (60,000 pounds)
40 tons (80,000 pounds)
50 tons (100,000 pounds)

Hoist-System Configuration

The hoist-system configurations examined for this report included both single-point and two-point. The need to examine the single-point mode is obvious; its advantages are relative simplicity of operation, and minimal complexity of the hoist mechanism. Its major disadvantages in the load ranges considered are the large drum size necessary to support the entire load and the lack of load orientation control.

Of the many multipoint configurations possible, only two-point was examined for this report. The two-point configuration significantly reduces the required drum size and alleviates load orientation problems while minimizing system complexity. It was assumed early in the program that an examination of the single-point and two-point concepts would adequately demonstrate the comparative advantages and disadvantages of the candidate tension-members, and that the results would be applicable to systems with three or four suspension points. This assumption proved to be correct since the final ranking of the tension members was not influenced significantly by tension member size and load capacity.

Gust Load Factor

A gust load factor of 2.5 g is applied to the required load capacity.

Factor of Safety

A factor of safety of 1.5 is applied to the required load capacity.

Cone-Angle Factor

A cone-angle factor of 1.15 (corresponding to a cone angle of 30 degrees) is applied to the required load capacity in the two-point hoist-system configuration to account for differences between spacing of load-attachment points and spacing of aircraft-suspension points.

Center-of-Gravity Factor

A factor of 0.60 is applied to the load capacity in the two-point hoist system configuration to account for a 60-percent/40-percent split in tension-member loading due to expected variations in the position of the center of gravity of various loads.

Requir[illegible] Strengths

The [illegible] tension-member strengths are calculated by multiplying the l[illegible]acity under consideration by the proper factors. For the si[illegible]point mode, load capacities are multiplied by the gust load fa[illegible] and the factor of safety. In addition, for the two-point mode the load capacities are multiplied by the cone-angle factor and the center-of-gravity factor. The results are the following minimum ultimate tensile strengths of each tension member for the various load capacities and system configurations.

Hoist-System Configuration	Required Breaking Strength for Each Load Capacity: 30 Tons	40 Tons	50 Tons
Single point	225,000 lb	300,000 lb	375,000 lb
Two point	155,000 lb	207,000 lb	259,000 lb

Hook Weight

Hook weights have been estimated from Figure 2, which was developed using information on present similar hooks:*

Hoist-System Configuration	Estimated Hook Weight for Each Load Capacity 30 Tons	40 Tons	50 Tons
Single point	280 lb	340 lb	400 lb
Two point	190 lb	235 lb	280 lb

Fatigue Life

The expected number of hoist cycles at various discreet load levels, based on predicted helicopter mission requirements, is shown in Figure 3 (courtesy of The Boeing Company). This spectrum is appli cable to the fatigue life requirement of the proposed tension member only if the tension member must last the life of the helicopter. A trade-off of fatigue life requirements versus replacement costs and design compromises can be made in an effort to minimize the size and weight of the hoist system.

With reference to the tension-member concepts identified as a result of Task D of this program (pp. 14-33), fatigue behavior may be more or less defined. A confidence level may be assigned to each concept reflecting the amount of fatigue data available for similar materials and constructions. For example, the confidence level of wire rope, expressed as a percentage, should be near 100 percent since fatigue data are available for the rope sizes, constructions, and materials contemplated. On the other hand, fatigue data for synthetic ropes and tapes are almost nonexistent, and the confidence level should be well below 50 percent for these concepts. It is important to remember that a low confidence level does not indicate that a concept is less desirable from a fatigue standpoint, only that it is not possible to predict from available data that a tension member satisfying static strength criteria will last the required number of cycles under load. Further discussion of fatigue life trade-offs is found on page 41-45.

* T. Lancashire, R. T. Lytwyn, G. Wilson, and D. Harding, INVESTIGATION OF THE MECHANICS OF CARGO HANDLING BY AERIAL CRANE-TYPE AIRCRAFT, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, USAAVLABS Technical Report 66-63, August 1966, Contract DA 44-177-AMC-312(T), AD 643 027.

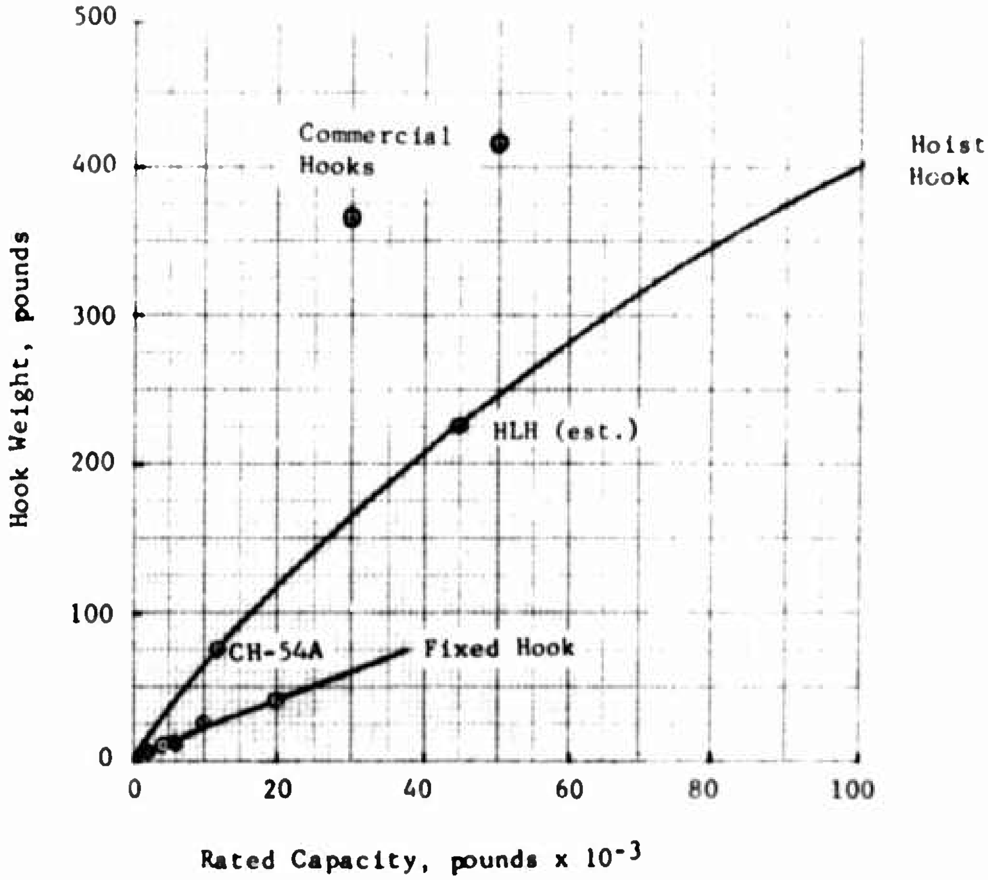


Figure 2. Estimated Hook Weight Versus Load Capacity.

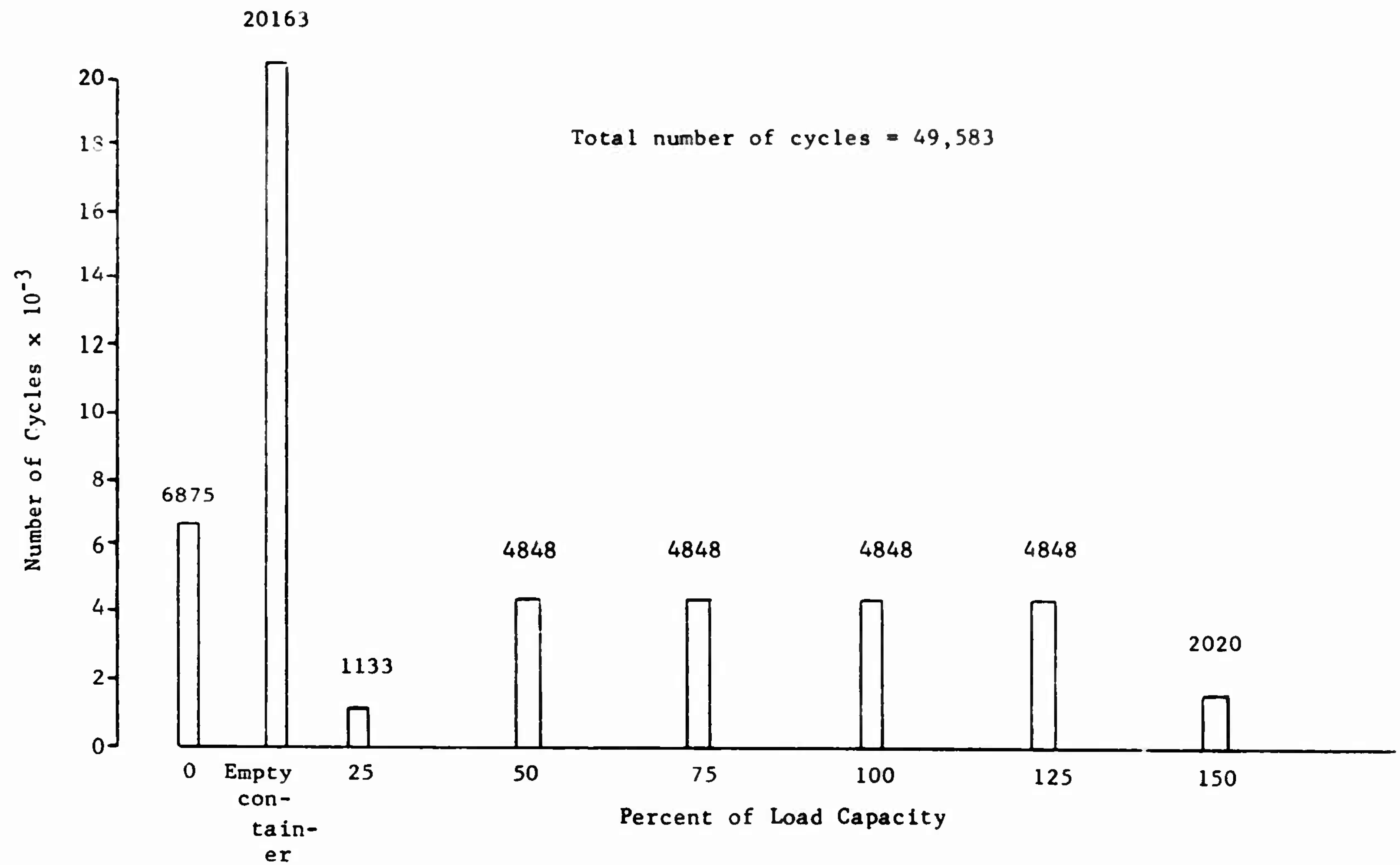


Figure 3. Tension-Member Load Spectrum.

TASK C: REVIEW OF CURRENT TENSION-MEMBER TECHNOLOGY

Personal Contacts

Personal contacts were important sources of information concerning (1) the current operational problems and experiences of carrying large loads external to a helicopter, (2) the current state of the art with respect to heavy-lift technology (primarily wire and synthetic ropes), and (3) the proposed advanced concepts for a heavy-lift helicopter tension member. The results of these contacts are reflected both in the matrix of parameters and in the discussion of various tension-member concepts that are included later in this report. Personal contacts made during this program included:

Alliance Webbing Co.	- New York, New York
American Chain and Cable Company	- Adrian, Michigan
Boeing Company - Vertol Division	- Philadelphia, Pennsylvania
Briles Wing & Helicopter, Inc.	- Santa Monica, California
Buffalo Weaving and Belting Company	- Buffalo, New York
Celanese Fibers Company	- New York, New York
Columbian Rope Company	- Auburn, New York
Eastern Rotorcraft Corporation	- Doylestown, Pennsylvania
E. I. du Pont de Nemours and Company	- Wilmington, Delaware
Goodyear Tire and Rubber Company	- Akron, Ohio
Naval Air Engineering Center	- Philadelphia, Pennsylvania
Naval Ship Research and Development Laboratory	- Annapolis, Maryland
Northrop Corporation	- Hawthorne, California
Phoenix Trimming Company	- Chicago, Illinois
Samson Cordage Works	- Boston, Massachusetts
United Aircraft, Sikorsky Division	- Stratford, Connecticut
U.S. Army Aviation, 291st Aviation Co.	- Fort Sill, Oklahoma
U.S. Naval Air Missile Test Center	- Point Mugu, California
Western Helicopters. Inc.	- San Bernardino, California

Literature Search

Part of the effort performed during Phase I was the conduct of literature searches of existing tension-member technology applicable to heavy-lift helicopters. The sources of information used were the Technical Abstract Bulletin, 1969 - present; Engineering Index, 1968 - present Defense Documentation Center,* 1966 - present; Applied Science and Technology Index, 1968 - present, and the U.S. Government Research and Development Reports, 1968 - present. In addition, applicable trade literature published by manufacturers of cordage and wire rope was reviewed.

Approximately 50 reports and articles have been obtained and reviewed. A bibliography is included later in this report.

*DDC search utilized the following key words: helicopters, helicopter hoists, helicopter slings, and cables (mechanical).

TASK D: IDENTIFICATION OF CANDIDATE TENSION-MEMBER CONCEPTS

As a result of the study of available literature and the discussions with those familiar with tension-member technology, a number of concepts were identified. These concepts ranged from the currently used wire rope to such schemes as a solid geared bar suspended vertically through the aircraft center of gravity. Each of these concepts was subjected to an initial "screening" during sessions with program personnel, until seven candidates remained which were considered worthy of further study. These candidates included: Wire Rope, Wire-Rope Belt, Steel Tape, Synthetic Rope, Synthetic Tape, Roller Chain, and Jointed Links.

Figures 4 and 10 illustrate the several tension-member concepts. Details of the sizes and physical properties of these tension members are found in Tables I through VII, following the discussion of each concept.

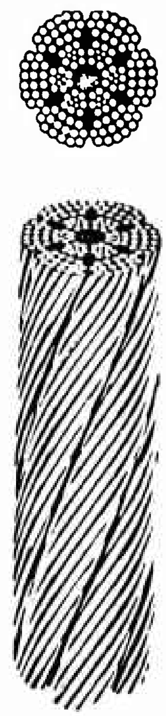
It should be noted that detailed discussions of synthetic materials throughout the report make no mention of du Pont's new fiber PRD-49. This new material was introduced commercially after the preliminary concept evaluations were carried out. A discussion of the impact of this material on tension-member technology may be found in the section of this report entitled "DISCUSSION OF PRACTICAL CONSIDERATIONS".

Wire Rope

Wire rope of a nonrotating construction as shown in Figure 4 offers the advantage of off-the-shelf availability to handle the proposed external loads. Wire rope in general offers good strength-to-weight ratio and resistance to thermal effects. Flight stability should be good for all flight attitudes because of the round shape, and in case of emergency, the rope could be effectively guillotined. The rope would display sufficient flexibility to provide ease in handling during hookup operations and routine maintenance. End connections such as swage fittings are readily available to allow attachment to a swivel at the hook end.

The rope could be easily stored on a drum; however, a level-wind mechanism would be required. A single layer on a grooved drum would provide better fatigue life than a multiple layer system. Both the need for a level-wind mechanism and the drum size may be considered somewhat detrimental due to weight and space considerations.

A more serious detriment would be the reaction of the rope due to a release of the load before relieving tension (emergency hook release). It is conceivable that the rope would "snap back" into the fuselage or, more seriously, into the plane of the rotor. In any event, cable backlash or open kinks in the wire might readily occur, requiring replacement of the member and possible repair of the winch mechanism.



Nonrotating construction (e.g., 6 x 16/6 x 10 flattened strand) possibly with conductors in the center

Figure 4. Wire-Rope Tension Member.

TABLE I. WIRE ROPE TENSION-MEMBER PHYSICAL CHARACTERISTICS

	Physical Characteristics for Six Load Cases					
	30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Rope diameter*, in.	1-3/8	1-5/8	1-13/16	1-3/16	1-3/8	1-1/2
Breaking strength*, lb x 10^{-3}	225	304	376	166	225	262
Weight* (100 ft), lb	377	525	654	281	377	449
Elastic modulus, psi x 10^{-6}	13.5	13.5	13.5	13.5	13.5	13.5
Spring rate, lb/in.(@ ℓ = 100 ft)	10,450	14,500	18,100	7,760	10,450	12,400
Minimum bend radius, in.	16.5	19.5	21.8	14.3	16.5	18.0
Metallic area*, in.^{2}	0.93	1.29	1.61	0.69	0.93	1.10

* Reference pp. 108-110.

Another problem area is that of static electricity discharge which would seriously endanger the safety of the hookup crew if adequate grounding or insulation were not provided.

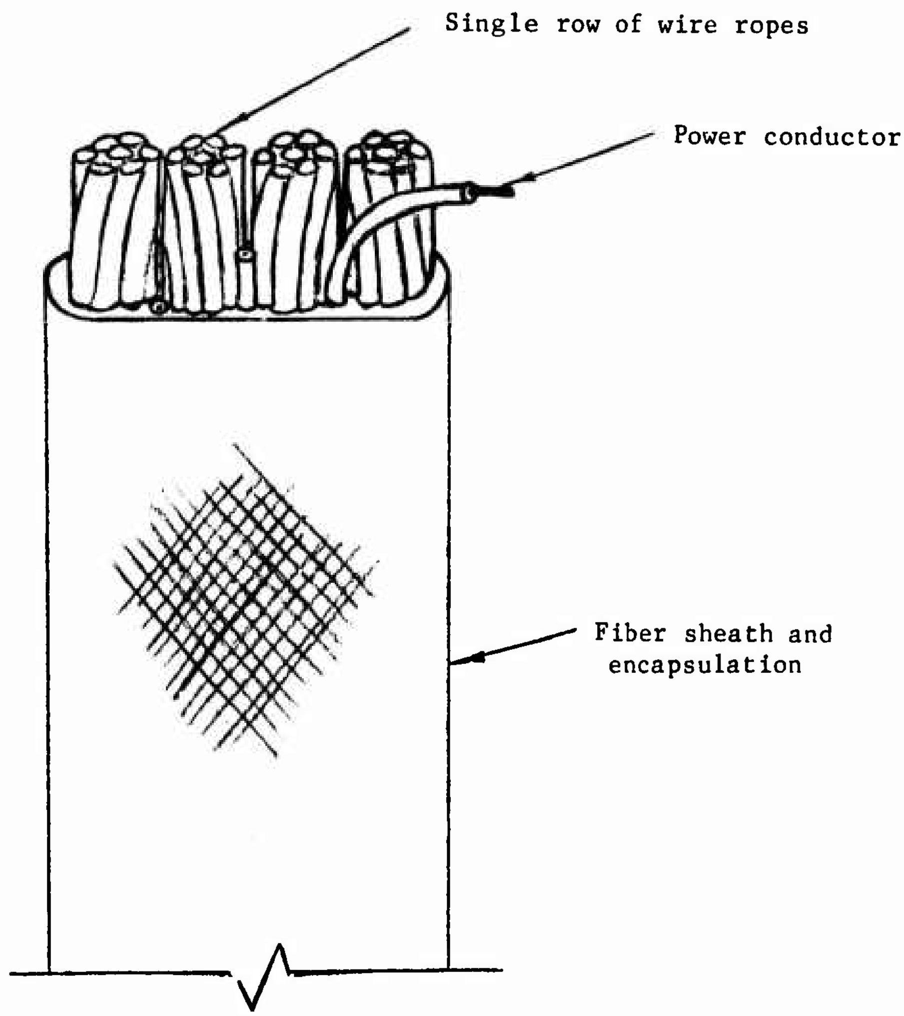
A nonrotating construction would be required if a single wire rope were used as a tension member. Otherwise, use of a swivel would allow a rope of conventional construction to unlay, thereby drastically altering the load distribution among the wires and adversely affecting the rope breaking strength. Unfortunately, nonrotating constructions are generally less dense than other types due to the use of two or more layers of strands with alternating right and left helices. Also, contrahelically wrapped strands produce multiple cross-wire notching points within the rope, resulting in poorer bending fatigue life. Thus, a nonrotating type of rope probably would be larger in diameter and possibly heavier than other rope types with similar strength and fatigue characteristics.

Use of conventional rope constructions for a tension member would require that the ropes be used in multiples of two, half left lay and half right lay, to provide a torque-free, nonrotating assembly. A pair of cables deployed from two drums, such as the concept under development in the current Heavy Lift Helicopter/Advanced Technology Components Cargo Handling System program, is one approach. This system may have a weight disadvantage due to the necessity for two drums and level wind systems for each hoist cable. Another approach is the wire-rope belt discussed below.

A number of wire materials are available, including carbon steel, various stainless steels, and titanium. Essentially, the desired material must have a combination of high strength and good ductility (for maximum fatigue life), together with adequate corrosion protection. Extensive testing by Battelle and practical field experience have shown that carbon steel offers the best combination of strength and ductility; drawn galvanized carbon steel is selected for its corrosion resistance. For the rope sizes in question, a wire strength level of 280,000 psi is catalogue available, while actual wire strengths of about 325,000 psi are now being obtained for ungalvanized wire rope of the sizes studied in this report (an increase of about 15 percent). This latter strength level has been utilized for calculation of required rope diameters. It is conservatively expected that the strength lost due to galvanizing will be more than made up in the continued development of higher strength wires.

Wire-Rope Belt

Wire rope of conventional construction with an independent wire-rope core (IWRC) could also be used in a flat belt configuration with several ropes bonded together and enclosed in a sheath. (See Figure 5.) This configuration would offer the advantage of using smaller diameter ropes of higher-strength wire to improve the strength-to-weight ratio. As for single wire ropes, a strength level of approximately 325,000 psi is assumed. The belt could be wound in layers on a relatively small drum without the need for level-wind mechanisms, and it would be more flexible



Two left-lay and two right-lay ropes used to provide a non-rotating belt.

Figure 5. Wire-Rope-Belt Tension Member.

TABLE II. WIRE-ROPE-BELT TENSION-MEMBER PHYSICAL CHARACTERISTICS

	Physical Characteristics for Six Load Cases					
	30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Diameter of each rope,* in. (4 ropes)	11/16	13/16	15/16	9/16	11/16	3/4
Belt breaking strength,* lb $\times 10^{-3}$	232	320	416	156	232	271
Weight* (100 ft), lb	353	481	641	240	353	416
Elastic modulus, psi $\times 10^{-6}$	14.5	14.5	14.5	14.5	14.5	14.5
Spring rate, lb/in. (@ ℓ = 100 ft)	10,600	14,500	19,300	7,300	10,600	12,600
Minimum bend radius, in.	8.25	9.75	11.25	6.75	8.25	9.0
Metallic area,* in.^{2}	0.88	1.20	1.60	0.60	0.88	1.04

* Reference pp. 108-110.

and easier to handle during hookup operations. The belt would offer good resistance to thermal effects, and the bonded sheath would protect the steel member from corrosion and abrasion. Right- and left-lay ropes could be used in pairs to provide a torque-free belt. Electrical conductors could readily be incorporated into the belt for communications or electrical power to the hook. The encapsulation of the belt would help to relieve some of the problems of static electricity discharge during hookup operations by insulating the metallic tension elements; the danger of contact with the hook would not, however, be reduced.

Gimbaling of either the winch mechanism or a fairlead roller would, however, be required to allow even distrubution of loads in the member. Flight stability of the member might be adversely affected because of the flat shape.

Steel Tape

A solid steel tape of high tensile strength (300,000 psi), as shown in Figure 6, is another tension member candidate. A steel tape would have good resistance to thermal effects and would also offer an attractive strength-to-weight ratio. Internal wear would be nonexistent, and resistance to abrasion would be good. The tape would be relatively easy to visually inspect for exterior damage and would lend itself well to inspection by other nondestructive techniques. The tape would also offer excellent resistance to torsional problems and would be kink resistant. In addition, the tape could be stored in layers on a drum with no need for a level-wind mechanism.

The steel tape would, however, require that the winching mechanism be gimbaled to provide uniform loading on the tension member. The relatively large flat surface exposed to the airstram could present unfavorable flight characteristics. Static electricity discharge would present a problem to the hookup crew if adequate grounding or insulation were not provided. Also, a steel tape could prove to be extremely difficult for a crew to handle under field conditions. Power conductors to the hook would probably have to be supplied from a separate system.

Synthetic Rope

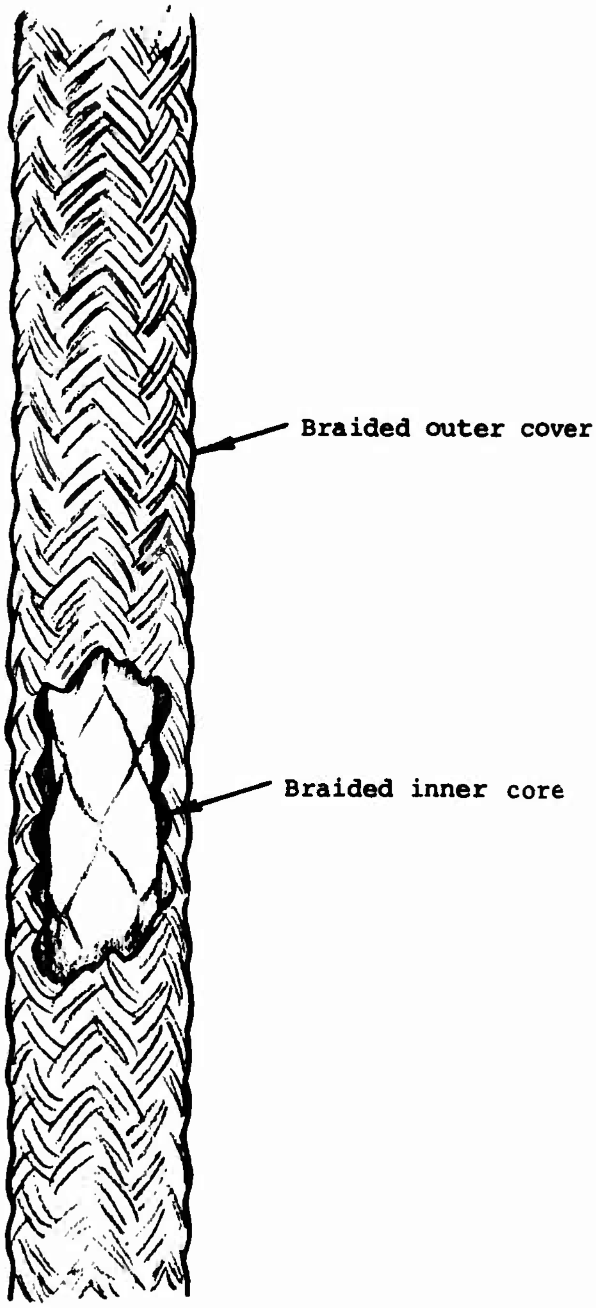
Rope or cable made from such synthetic fibers as nylon, Dacron, polyester, polyethylene or polypropylene exhibits several advantages over wire rope for the helicopter-load tension-member application. In an emergency situation, it would be quite easy to sever the rope using a guillotine, the sharpness of the blade probably being the most important requirement. The "double-braid" construction, in which a separate outer braided wrap encloses a central braided core (see Figure 7), has excellent kink resistance. At the same time, rope with this construction would not impart a

Assumed material tensile strength =
300,000 lb/in.^{2}

Figure 6. Steel-Tape Tension Member.

TABLE III. STEEL-TAPE TENSION-MEMBER PHYSICAL CHARACTERISTICS

	Physical Characteristics for Six Load Cases					
	30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Thickness, in.	0.125	0.125	0.125	0.125	0.125	0.125
Width, in.	6	8	10	4.14	5.52	6.91
Breaking strength, lb x 10^{-3}	225	300	375	155	207	259
Weight (100 ft), lb	255	340	425	177	234	292
Elastic modulus, psi x 10^{-6}	30.7	30.7	30.7	30.7	30.7	30.7
Spring rate, lb/in.(@ ℓ = 100 Ft)	19,200	25,600	32,000	13,300	17,700	22,000
Minimum bend radius, in.	20	20	20	20	20	20
Metallic area, $in.^2$	0.75	1.00	1.25	0.52	0.69	0.86
Material ultimate tensile strength, psi x 10^{-3}	300	300	300	300	300	300



Double braid construction such as manufactured by Samson Cordage Works with polypropylene core and polyester cover.

Figure 7. Synthetic-Rope Tension Member.

TABLE IV. SYNTHETIC-ROPE TENSION-MEMBER PHYSICAL CHARACTERISTICS

	Physical Characteristics for Six Load Cases					
	30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Rope diameter,* in.	2-3/4	3-1/4	4-3/4	2-3/8	2-5/8	3
Breaking strength,* lb x 10^{-3}	225	303	384	164	207	264
Weight* (100 ft), lb	206	280	357	150	188	240
Elastic modulus**, psi x 10^{-6}	0.19	0.19	0.19	0.19	0.19	0.19
Spring rate, lb/in. (@ ℓ = 100	940	1,310	1,750	700	860	1,120
Minimum bend radius, in.	11	13	15	9.5	10.5	12
Rope area,* $in.^2$	5.94	8.30	11.05	4.43	5.41	7.06

* Ref. pp. 113-114.

** Linear approximation based on stress and strain values at failure, stress based on gross rope area.

torque to the load, as the rope braid is torque-free. Synthetic rope will not corrode, as such, although each synthetic material is susceptible to degradation from certain acids and/or alkalis. Susceptibility to the effects of the sun's ultraviolet radiation would probably necessitate an outer protective coating, such as urethane, on the synthetic rope. From the standpoint of safety of ground personnel during load acquisition and release, the alleviation of the static electricity discharge problem is probably one of the most significant advantages of a synthetic fiber tension member.

Perhaps the biggest drawback inherent in synthetic fiber rope is its highly elastic nature, which leads to large elongations under load and a high stored energy situation. For example, a typical double-braid rope of 2-3/4-inch diameter loaded to 30 tons (27% of UTS) exhibits an elongation of about 10%, giving a stored energy of 5.6×10^5 foot-pounds. This high quantity of stored energy presents a problem of potentially serious nature if the rope were to break or the hook disengage under tension, sending the rope back up toward the helicopter fuselage or rotors. Another unknown exists in the prediction of rope fatigue life; little is known of the fatigue behavior of large synthetic ropes subject to repeated bending.

Synthetic rope has about twice the strength-to-weight ratio of comparable wire rope, meaning that for a given load capacity, the weight of synthetic rope will be half that of wire rope. (New fibers produced by du Pont and Celanese show promise of a further increase in strength-to-weight ratio.) Additionally, synthetic rope can be wrapped over significantly smaller drum diameters than can wire rope, allowing both a space and weight savings in the hoist system. Because of its flexibility and its generally smooth outer surface, synthetic rope would be extremely easy to handle during maintenance or replacement. On the other hand, its flexibility would impose a design problem for any sort of integral power conductors because of both bending and tensile elongation.

A synthetic which was considered and then rejected is glass fiber rope. While the strength-to-weight ratio is significantly greater than that of other synthetic-fiber ropes, glass-fiber rope cannot be successfully bent over small diameter sheaves or drums without either breaking up or having an unacceptably short fatigue life. The drum sizes or other storage would therefore be too large to be accommodated in even a large helicopter.

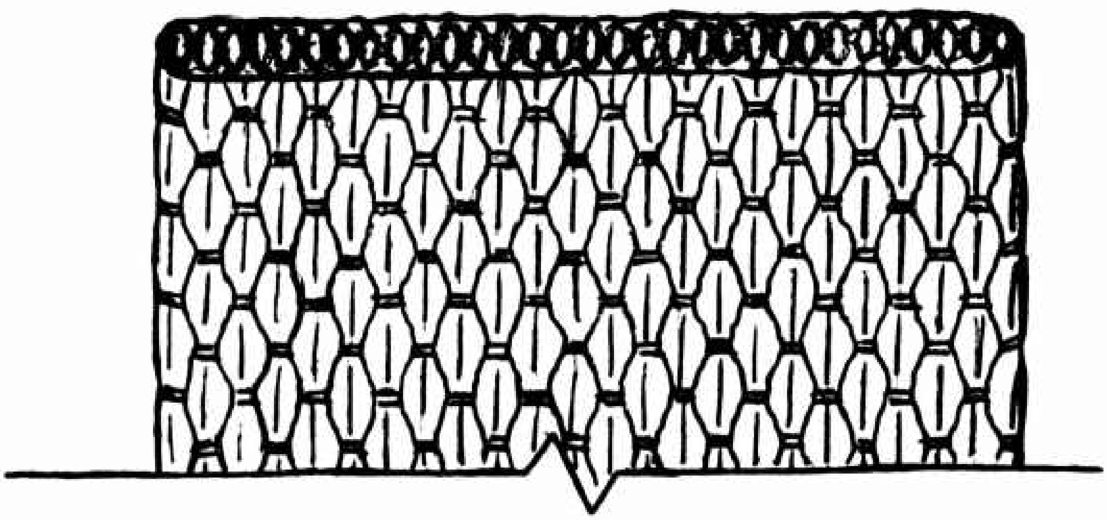
Synthetic Tape

A synthetic tape configuration might be either a flat woven band of some synthetic fiber, as shown in Figure 8, or a flat bundle of synthetic ropes enclosed in a woven cover. In both cases, a binding material could be used to assure a stable configuration. Many of the comments made in the discussion of synthetic rope apply equally to synthetic tape. For example, the advantages of flexibility, kink resistance, and ease of handling would be found in synthetic tape. In addition, a tape could be wound on a still smaller diameter drum, allowing further savings in space. Of course, this means an increasing driving torque would be necessary to maintain constant speed to the hoisting load, but this increase might not pose the problem it seems at first. For example, a representative synthetic tape with a breaking strength of 375,000 pounds is 13 inches wide by 0.4 inch thick (satisfactory for the requirements of a single-point, 50-ton hoist). With a drum diameter of 11 inches, approximately 23 wraps of the tape upon itself would be required to reel in 100 feet, bringing the final lifting diameter to 30 inches. This final diameter would still be significantly lower than that required for a drum for a wire rope (1-13/16-inch rope, 24-to-1 diameter ratio, 44-inch drum), thus reducing the required hoist drive torque.

Perhaps the area of most concern regarding tape is the effect of its flat shape on its flight stability. It might be that for some extended lengths and tape tensions, high drag and unstable flutter conditions could develop that would restrict the helicopter operations. And finally, the problem of large elongations under load and the resulting stored energy hazard would be equally as significant as in synthetic rope.

Roller Chain

Roller chain, as shown in Figure 9, might seem a most unlikely candidate for a helicopter tension member, but it has several advantages over other tension-member concepts. First, due to the roller chain construction, the hoisting mechanism would be of the positive drive type. As a result, the storage could be loose, as in a bin or on a rack, with little or no back tension on the roller chain. There would be no requirement for level wind or other sophisticated mechanisms to assure proper feed-in or feed-out. At the same time, there would be no stored energy in the retracted tension member, reducing the hazard to maintenance personnel. Second, the chain is quite high in modulus, meaning low stored energy under load and probable elimination of this problem. However, some sort of gimbaling of the hoist would be required to avoid high side loads being transmitted to the helicopter. Finally, damage to a roller chain could easily be located and repaired, without replacing the entire tension member.



Tape comprised of parallel bundles of polyester fibers with a woven binder.

Figure 8. Synthetic-Tape Tension Member.

TABLE V. SYNTHETIC-TAPE TENSION-MEMBER PHYSICAL CHARACTERISTICS

	Physical Characteristics for Six Load Cases					
	30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Thickness, in.	0.40	0.40	0.40	0.40	0.40	0.40
Width, in.	7.65	10.20	12.75	5.25	7.05	8.80
Breaking strength,* lb x 10^{-3}	225	300	375	155	207	259
Weight* (100 ft), lb	144	192	240	99	132	165
Elastic modulus, psi x 10^{-6}	0.63	0.63	0.63	0.63	0.63	0.63
Spring rate, lb/in. (@ ℓ = 100 ft)	1,600	2,150	2,680	1,100	1,480	1,850
Minimum bend radius, in.	5.6	5.6	5.6	5.6	5.6	5.6
Tape area,* in.^{2}	3.06	4.08	5.10	2.10	2.81	3.52

* Ref. pp. 115-116.

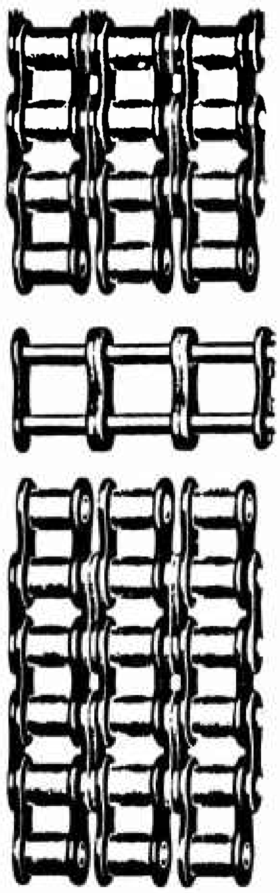


Figure 9. Roller-Chain Tension Member.

TABLE VI. ROLLER-CHAIN TENSION-MEMBER PHYSICAL CHARACTERISTICS

	Physical Characteristics for Six Load Cases					
	30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
ASA number *	160-4	160-6	200-4	160-3	160-4	200-3
Breaking strength,* lb x 10^{-3}	232	348	380	174	232	285
Weight * (100 ft), lb	2530	3780	4290	1900	2530	3230
Elastic modulus, psi x 10^{-6}	6.9	6.9	7.6	6.9	6.9	7.6
Spring rate, lb/in. (@ ℓ = 100 ft)	14,000	21,000	25,300	10,500	14,000	19,000
Minimum bend radius, in.	7	7	8.5	7	7	8.5
Width, in.	9.64	14.26	11.89	7.34	9.64	9.08
Metallic area, $in.^2$	2.44	3.65	3.99	1.83	2.44	2.99

* Ref. pp. 117-118.

It is unlikely that power conductors could be made integral with a roller-chain tension member. This would require a separate hoist system for the power conductor to the hook. Roller chain has about the lowest strength-to-weight ratio of all the concepts considered, about one-sixth that of wire rope and one-tenth that of synthetic braided rope. Lubrication of the moving parts is usually necessary with roller chain, increasing the chances of wear on the bearing surfaces in a dusty environment.

Jointed Links

The jointed-link concept for a helicopter tension member, as shown in Figure 10, has many of the same advantages as the roller-chain concept. A jointed-link member with universal joints would allow the member flexibility under side loads, while facilitating easy storage either in a bin or on a rack. The enlarged ends would form the bearing surfaces for a positive hoist drive so that no back tension would be necessary in the storage system. Maintenance could be in the form of an occasional lubrication of the universal joints, and damaged links could easily be removed and replaced without replacing the entire tension member. The advantages of high modulus and the consequent low stored energy under tension have already been discussed. The material is assumed to be heat-treated carbon steel of a nominal 150,000-psi strength level.

Unfortunately, the jointed links would likely be quite heavy due to the high bending loads and bearing loads near the universal joints. In addition, judging from the costs listed for roller chains, jointed links would be quite expensive. Integral power conductors would be difficult to design for this tension-member concept, probably necessitating a separate system to transmit power to the hook. Finally, torsional rigidity would require some form of swivel at the hook attachment point.

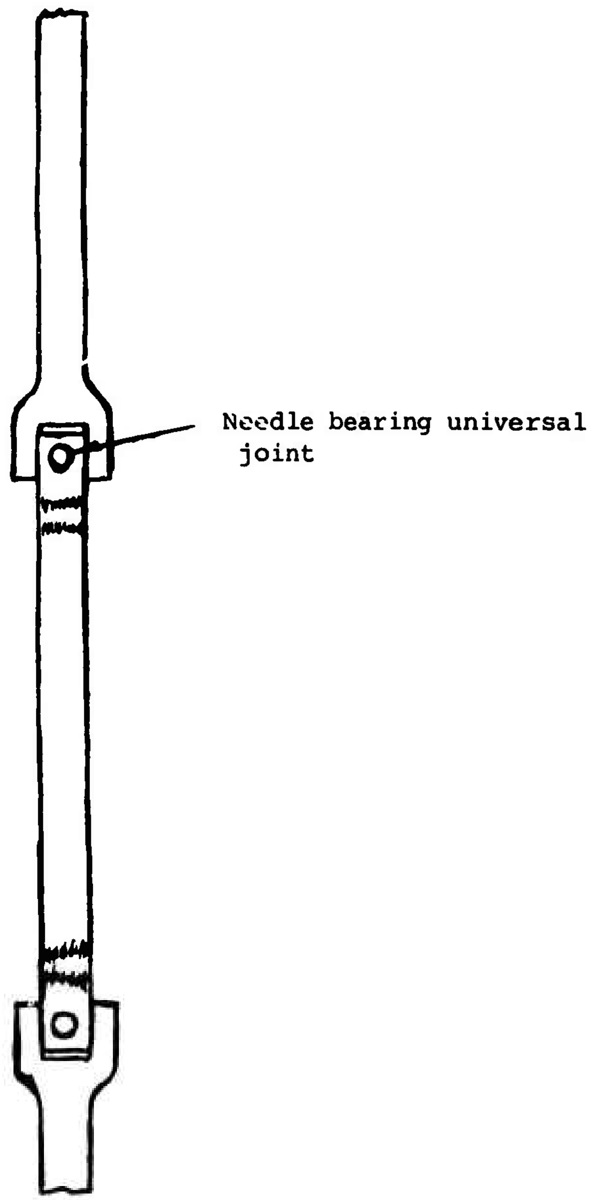


Figure 10. Jointed-Link Tension Member.

TABLE VII. JOINTED-LINK TENSION-MEMBER PHYSICAL CHARACTERISTICS

	Physical Characteristics for Six Load Cases					
	30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Link diameter, in.	1.38	1.60	1.78	1.15	1.33	1.48
Breaking strength, lb x 10^{-3}	225	300	375	155	207	259
Weight* (100 ft), lb	600	800	1000	415	550	690
Elastic modulus, psi x 10^{-6}	20.0	20.0	20.0	20.0	20.0	20.0
Spring rate, lb/in.(@ ℓ = 100 ft)	25,000	33,000	41,500	17,000	23,000	29,000
Minimum bend radius, in.	24	24	24	24	24	24
Link area, in.^{2}	1.50	2.00	2.50	1.03	1.38	1.73
Material ultimate tensile strength, psi x 10^{-3}	150	150	150	150	150	150

* Estimated at 2.35 times weight of steel tape to account for extra material at link ends.

TASK E: CONCEPT EVALUATION TECHNIQUE

A weighted-parameter analysis was chosen as the means for evaluating the candidate tension-member concepts. The important parameters identified during Tasks A and B were reexamined, combined where appropriate, and grouped under the general categories of Safety, Function and Operation, and Cost and Design Compromise. Both the categories and parameters were assigned values reflecting their relative importance to the external load-carrying function. Then the candidate concepts were judged with respect to each parameter and assigned a value to indicate the expected performance of the tension member for each parameter. The tension-member concepts were then compared by multiplying together the category, parameter, and concept evaluation numbers and summing the resulting scores for each concept. The total score was then divided by the maximum possible score (represented by an evaluation of 10 for every parameter) and expressed as a percentage.

There are both advantages and disadvantages in choosing the weighted-parameter analysis technique. Obviously, the analysis of concepts for a specific parameter is made easier if straightforward quantitative engineering techniques can be employed. Thus, for example, the analysis of tension-member concepts for stored energy (pp.107-121) results in a specific hook release load which will endanger the aircraft and crew for each concept. Comparison of these loads enables a quantitative evaluation of the relative stored energy problem for each concept. Note, however, that there is no mechanism available for eliminating a concept outright for an insoluble stored energy problem. Because of this drawback in the weighted-parameter analysis technique, a separate section of this report (pp. 41-45) is devoted to discussing the practical considerations in developing each of the tension-member concepts. The developmental risks are covered, with reference to specific time frame, and judgements are made to eliminate concepts for overriding practical factors, regardless of their ranking in the strict weighted-parameter analysis. The analysis technique is, then, a means of identifying the important tension-member parameters and the strong and weak points of each concept with respect to those parameters; this approach allows a somewhat subjective final practical concept evaluation.

PHASE II
EVALUATION OF TENSION-MEMBER CONCEPTS

PARAMETER QUESTIONS

The parameters selected during the Phase I work for evaluating the various tension-member concepts were reevaluated, combined, and grouped into the three major categories: Safety, Function and Operation, and Cost and Design Compromise. Within these categories, each parameter was analyzed to identify its importance to the total hoisting system and to establish a suitable definition of the parameter. The categories, revised parameters, and assigned weights are shown in Table VIII. The following questions pertain to each parameter that was utilized in evaluating each tension-member concept. The number preceding each parameter indicates the parameter order based on overall weight value as shown in Table VIII. Page numbers indicate the location in the report of the discussion and evaluation of tension-member concepts for each parameter.

Safety

1. Ease of guillotining (p. 106)

   How difficult will it be to cut the tension member at the aircraft (mechanically or electrically/explosively) when an emergency situation arises?

2. Stored energy-elasticity (p.107)

   How likely is it that the energy stored in the tension member will cause the hook to be launched into the aircraft fuselage or rotors if there is an inadvertent or emergency release of cargo?

4. Resistance to shock loading (p.123)

   Will the tension member survive impact loading such as that due to in-flight gusts or violent flight maneuvers?

5. Resistance to thermal damage (p.127)

   Will there be any change in tension-member physical properties, particularly degradation in strength, due to heat that may be developed either internally to the tension member construction or externally due to rubbing against components of the hoist system?

6. Resistance to environmental damage (p.130)

   Will sunlight, sand and dust, moisture, and extremes in temperature have detrimental effects on the tension member?

TABLE VIII. TENSION-MEMBER PARAMETERS BY CATEGORY AND WEIGHTING

Category	Category Weight	Parameter	Parameter Weight	Product of Category and Parameter Weights *
Safety	10	Ease of Guillotining	1.0	10
		Stored Energy - Elasticity	1.0	10
		Resistance to Shock Loading	0.7	7
		Resistance to Thermal Damage	0.7	7
		Resistance to Environmental Damage	0.7	7
		Static Electricity	0.5	5
		Inspection	0.5	5
		Abrasion Resistance	0.3	3
		Susceptibility to Gunfire	0.3	3
Function and Operation	8	Aerodynamic Considerations	1.0	8
		Projected Hoist Complexity	0.6	5
		Torsional Characteristics	0.4	3
		Resistance to Shock Unloading	0.4	3
		Ease of Handling	0.3	2
		Maintenance	0.1	1
Cost and Design Compromise	7	Projected System Weight	1.0	7
		Projected System Size	0.7	5
		End Connections Required	0.6	4
		Acceptance of Power Conductors	0.4	3

*Products are rounded off to give integer values.

8. Static electricity (p.133)

Since no successful means has been found to reduce the static charge potential on the aircraft to below the danger level, will the tension member conduct this charge in a manner hazardous to ground personnel?

9. Inspection (p.134)

Can the tension member be easily inspected for damage, both internal and external, that might result in shortening its useful life?

13. Abrasion resistance (p.139)

Is the tension member sufficiently abrasion resistant to withstand wear it may encounter from contact with rocks, vegetation, and components in the hoist system?

14. Susceptibility to gunfire (p.140)

How vulnerable is the tension member from the standpoint of projected area, and how will a hit by a 12mm projectile affect the breaking strength?

Function and Operation

3. Aerodynamic considerations (p.122)

Will the aerodynamic behavior of the tension member result in vibration or flutter that may lead to thermal or fatigue damage to the tension member; and will drag be a problem?

10. Projected hoist complexity (p.135)

Can the tension member be reeled in and out easily without complicated level-wind mechanisms or reeving?

15. Torsional characteristics (p.143)

Is the tension member antirotative in the sense that loading will not induce torsional moments on the cargo? Will the tension member accept turning of the load without undue stresses (is a hook swivel necessary)?

16. Resistance to shock unloading (p.144)

Will the tension member kink, snarl, or "birdcage" due to release of tension, either when a load is "bounced" or when the tension member enters storage in the hoist?

18. Ease of handling (p.147)

How difficult is it for a ground handler to move the hook to an attachment point on the cargo, and can maintenance personnel easily install, inspect, and remove the tension member (an indication of tension member weight, flexibility and surface configuration)?

19. Maintenance (p.148)

Is the tension member likely to require a great deal of maintenance, and how difficult will the maintenance be either in the field or at the main base?

Cost and Design Compromise

7. Projected system weight (p.132)

How do both tension member and total system weights compare for the various concepts?

11. Projected system size (p.137)

Will the limitations on tension member bending stresses require undesirably large components in the hoist, fairlead, or storage systems?

12. End connections required (p.138)

How much increased load capacity is required of the tension member to account for less than 100-percent efficiency of the end connections, and what weight penalty do the end fittings impose on the system?

17. Acceptance of power conductors (p.145)

Can the power conductors be integral with the tension member (either imbedded into or attached to the tension member) without compromising either strength or safety, or must the conductors be extended and retracted by a separate system?

CONCEPT ANALYSIS

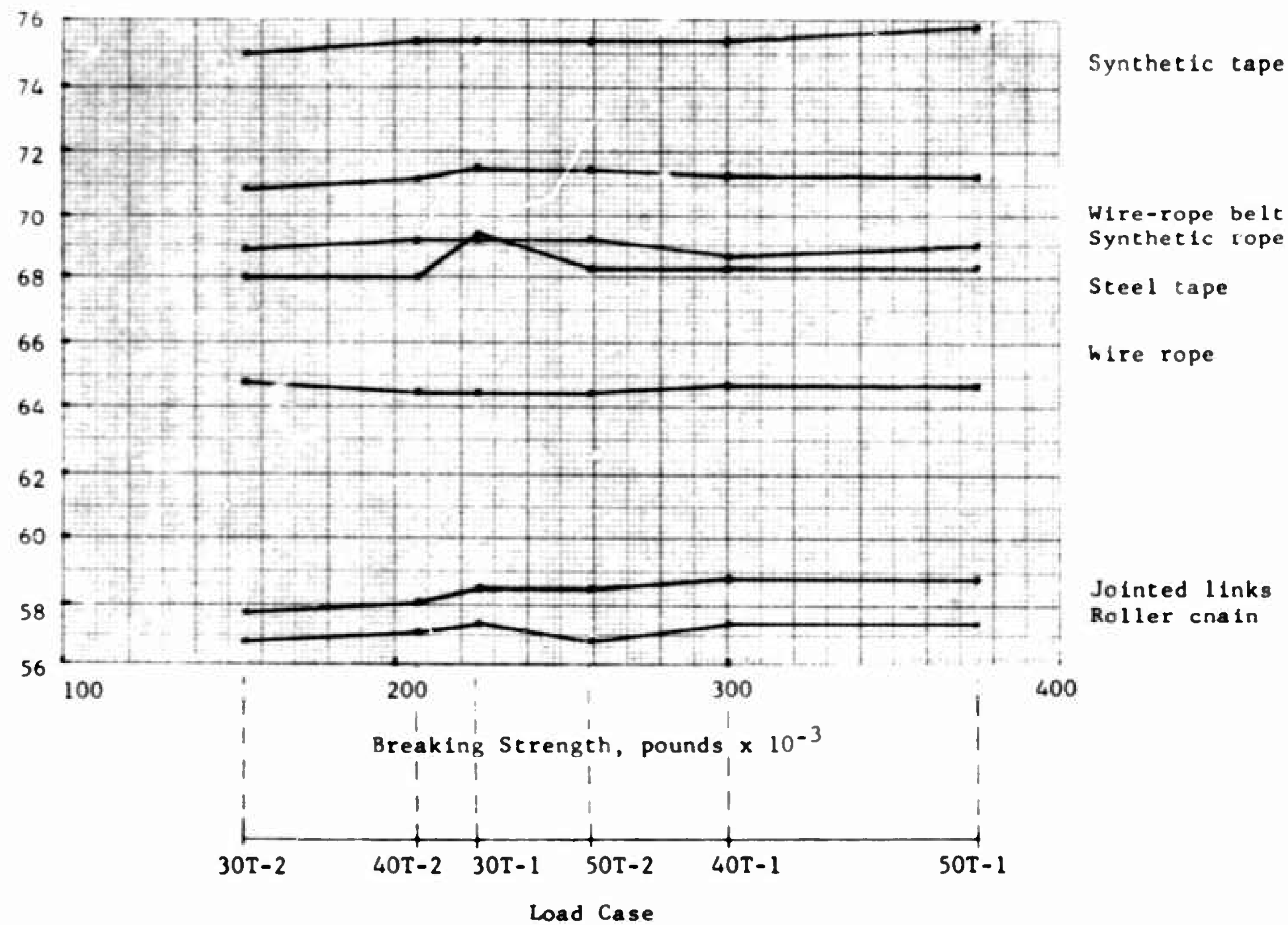
Each of the seven candidate tension-member concepts was analyzed to determine its relative acceptability with regard to each of the parameters listed in Table VIII. A detailed discussion of this study is presented in Appendix II. Tension member physical properties used in this analysis have been presented in Tables I through VII. As a result of this investigation, each concept was given a value that reflects its expected comparative performance for each parameter. These values are tabulated in Appendix III.

Following the procedures of the weighted-parameter technique of evaluation, the combined category and parameter weights listed in Table VIII were multiplied by the parameter values and the products summed. For example, examining wire rope for the 30-ton single-point load case:

Category	Parameter	Combined Category and Parameter Weight	Concept Evaluation	Score
Safety	Ease of guillotining	10	8	80
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
Function and Operation	Ease of handling	2	6	12
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
			Total Score =	633

The maximum score attainable under this technique of evaluation is 980. Therefore, the total score for the example above may be expressed as 64.5 percent of the highest possible score. The percentage scores for each tension-member concept and load case are summarized in Table IX and are shown graphically in Figure 11.

The results of this analysis indicate that the synthetic tape and wire-rope belt concepts are most promising for all load cases and suspension configurations.



igure 1 Evaluation of Tension-Member Concepts by Weighted-Parameter Technique.

TABLE IX. TENSION-MEMBER CONCEPT SCORES

Concept	Load Case 30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
A. Wire rope	64.5	64.7	64.7	64.8	64.5	64.5
B. Wire-rope belt	71.5	71.3	71.3	70.9	71.2	71.5
C. Steel tape	69.4	68.3	68.3	68.0	68.0	68.3
D. Synthetic rope	69.2	68.7	69.0	68.9	69.2	69.2
E. Synthetic tape	75.4	75.4	75.8	75.0	75.4	75.4
F. Roller chain	57.4	57.4	57.4	56.8	57.1	56.8
G. Jointed links	58.5	58.8	58.8	57.8	58.1	58.5

DISCUSSION OF PRACTICAL CONSIDERATIONS

The weighted-parameter evaluation technique allows a convenient comparison of tension-member concepts for each load case. The concepts with the highest scores have been determined to be most promising because they have the fewest undesirable characteristics. However, in the form used, the evaluation technique does not allow for rejection of a concept on the grounds of an overriding disadvantage. This disqualification must come separately from an analysis of the concepts with regard to the practicality of solving whatever problems they might have. A discussion of each concept is in order to point out the assumptions that were made relative to the concept feasibility; if any of these assumptions later proves incorrect, that concept must be rejected. The initial discussions pertain to a 1980 development time frame, and are followed by discussions relating to 1975 and 1972 time frames, respectively.

Development Time Frame: Nine Years (1980)

The roller-chain and jointed-link concepts received the lowest scores because of a number of serious drawbacks. The weight of these tension members alone is sufficient to eliminate these concepts from further consideration. In addition, the required guillotine systems would be quite cumbersome. Other disadvantages include the requirement for mounting the chain hoist in gimbals to accommodate the cone angle; the expected large size of the hoist for the jointed-link tension member; and the maintenance requirements, handling difficulties, and electrical conductivity for both types of tension members. No developments are foreseen in the next nine years, either in materials or design, which might minimize the problems of weight, size, and complexity of these two tension-member concepts.

The wire-rope tension member came out fifth in the ranking. While this is a proven concept for hoist systems, several disadvantages exist for the helicopter application. A major drawback is the required size of the hoist system. Due to the bend radius requirements for good fatigue life, the hoist drum would have to be larger in diameter for wire rope than for the synthetic rope, wire-rope belt, or synthetic tape tension-member concepts; the hoist drum size, in turn, influences the helicopter size and the required hoist-drive torque. Other disadvantages of wire rope include the susceptibility to kinking and birdcaging upon shock unloading (this is a problem with the hoist cable on the CH-54 helicopter), the conductivity of static electricity, and the susceptibility to environmental damage. It is possible that, with the development of rope fabricating machines capable of stranding many very small wires (instead of fewer larger wires) coupled with the trend toward higher wire strengths, the problems of large bend radii and consequent hoist drum size will be alleviated. Still, the other disadvantages will remain.

The steel-tape tension-member concept ranked fourth. Probably the greatest drawback of this concept is its shape and the resulting aerodynamic problems. The great width of the steel tape results in high drag, and the tension member would probably experience undesirable flutter and vibration. These aerodynamic considerations are sufficient to eliminate the steel-tape concept from further consideration since there are no apparent solutions to the problem. The increases in material strengths over the next nine years are not expected to reduce the required tape width to the point where drag and flutter are negligible. Additionally, an increase in material strength is often associated with a decrease in ductility; the drum diameter would then have to be increased to maintain adequate fatigue life. Other problems include the susceptibility to damage which could result in the propagation of destructive fatigue cracks, poor power-conductor accommodation, electrical conductivity, and handling difficulties.

Third in the overall ranking is synthetic rope. The major disadvantages of this concept are stored energy and high probability of dangerous hook recoil upon inadvertent or emergency load release. There are indications that new, higher modulus and higher strength synthetics are on the developmental horizon. Specifically, du Pont has introduced a synthetic fiber (PRD-49) which has an elastic modulus of 20,000,000 psi and a strength level approaching 400,000 psi. It is safe to assume, therefore, that the problems of high stored energy and dangerous hook recoil might be alleviated. However, other drawbacks of synthetic rope include poor accommodation of power conductors, susceptibility to thermal and environmental damage, and difficulty of inspection for strength degradation.

Wire-rope belt is placed second in the overall ranking of tension-member concepts. The only major question regarding this concept is whether the wire-rope belt actually can be built to function properly when wrapped upon itself on a drum. While very small wire-rope belts have been fabricated in the past, adapting this concept to the heavy lift helicopter will probably require considerable design and experimentation effort. From the standpoint of state of development, the wire-rope belt earns a low level of confidence. The fatigue behavior of wire ropes is reasonably well known now, so that fatigue life prediction for this concept is straightforward. Development effort is necessary to evolve jacket materials capable of resisting the hostile operating environment and crushing loads on the drum. However, the belt can probably be built to operate properly on the hoist drum without experiencing damage due to the crushing loads, offering an excellent possibility for a useable tension member.

The highest ranked tension-member concept is synthetic tape. The major drawbacks of this concept are the stored energy and the aerodynamic considerations. Several possibilities exist for solving these problems. Dangerous hook recoil might be prevented by use of an energy-absorbing mass that would be suspended below the aircraft possibly two-thirds of the distance of the hook extension. This mass would have a central hole or slot through which the tension member would pass. Of course, a second small winch would be required to raise and lower the mass. In the event of an inadvertent or emergency load release, the recoiling hook would collide with the mass and be prevented from striking the aircraft. However, the best solution to the stored energy and hook recoil problems is to be found in the development of a new synthetic with higher strength and elastic modulus. As discussed previously in regard to synthetic rope, du Pont has introduced just such a fiber. With time and effort, this synthetic or others like it may eliminate the stored energy problem.

The aerodynamic problems of flutter and drag associated with the synthetic tape might be overcome by constructing the tape to form naturally a round or teardrop-shaped cross-sectional configuration when extended from the hoist drum. The tape would then "unfold" and flatten as it wrapped on the drum. Again, with a higher-strength, high-modulus synthetic, tape width can be reduced and drag minimized. For example, for the most severe

load case, 50T-1, the use of PRD-49 rather than Dacron reduces the required tape width from 8.80 inches to 2.34 inches while maintaining the same tape thickness. While much information concerning fatigue life, resistance to harsh environments, and fabrication needs to be developed, it is safe to say that synthetic tape will be a prime tension-member candidate in the nine-year time frame.

Development Time Frame: Four Years (1975)

For the four-year time frame, it is evident that only four of the seven tension-member concepts may be considered: wire rope, wire-rope belt, synthetic rope, and synthetic tape. The reasons for deleting the other three concepts are explained in the discussion of the nine-year developmental time frame.

With the exception of wire rope, the possible concepts rely on successful development in two distinct areas. These areas are the development of a synthetic material capable of eliminating the disadvantages of current synthetics for tension members, and the development of a workable tape hoist-drive system. The synthetic material development is already showing signs of great promise. As mentioned previously, du Pont has formulated a synthetic fiber (PRD-49) with an elastic modulus of 20,000,000 psi and a tensile strength approaching 400,000 psi. While this product is not without limitations for tension-member application (low compressive yield strength, compromising its use as rope-strand material, and high initial cost), development is continuing and four years should be adequate to minimize these drawbacks. However, the development of new wire materials and wire rope manufacturing techniques is also proceeding, particularly in the area of fatigue behavior. Since knowledge of the fatigue characteristics of the tension-member materials and constructions is so important to the safe and dependable operation of a tension member, it must be concluded that wire rope improvements will maintain a higher level of confidence than synthetic fibers over the next four years.

By contrast, continuing developments in the area of hoist drive systems should, over the next four years, result in a safe, reliable reel-type tape- or belt-drive hoist for large helicopter application. Because of its inherent advantages (much smaller tension-member-minimum-bend radius, more compact unit, no level-wind necessary) the reel-type hoist will then displace the drum and rope hoist as the "best" hoist-drive system.

Assuming that fabrication problems can be overcome, wire-rope belt is the first-ranked tension member for the 1975 time frame. Wire-rope belt combines the advantages of a reel-type hoist with the proven technological advantages of wire rope. At the same time, it does not have a stored energy problem, and aerodynamic drag is minimized. Torque problems are eliminated by having an equal number of ropes per belt of left- and right-hand lay. Although the outer coating and jacket should eliminate environ-

mental degradation (corrosion) of the ropes, the possibility of damage to the jacket suggests that galvanized wire might be utilized.

Synthetic tape is ranked second. It provides, again, a reel-type hoist drive. The important assumption is that a developmental synthetic, such as the new du Pont fiber, can be used in the construction of the tape; the confidence in this assumption leads to synthetic tape being ranked behind wire-rope belt. Also, the problem of aerodynamic drag might have to be alleviated in some novel way, such as "preforming" the tape to a low-drag configuration when extended.

Wire rope and synthetic rope rank third and fourth, respectively, for the four-year development period. Both have the disadvantage of needing a hoist drum with level-wind, and both are susceptible to some torsional problems. Wire rope ranks ahead of synthetic rope only because far more is known about the construction and fatigue behavior of the former; it is not likely that synthetic rope will "catch up" with the technology of wire rope in as short a time as four years.

Development Time Frame: One Year (1972)

Considering the state of the art of tension-member technology, only wire rope need be given serious thought for the needs of large helicopters twelve months from now. The state of development of wire rope has reached the point where a workable tension member of the 30- to 50-ton load range can be developed with a minimum of effort. Hoist technology is available; wire material and rope construction information is obtainable on an "off-the-shelf" basis. All that is necessary is to define specific functional criteria, design and built the rope, and prove it through laboratory and operational testing.

There is the small possibility that du Pont's PRD-49 can be developed to a practical point by the end of 1972. A minimum of effort would be necessary to adapt current hoist technology to the use of a high-modulus, high-strength synthetic rope. Even assuming that PRD-49 could be used in a rope construction such as the Samson double-braid (see Figure 7), a massive effort would be necessary to generate the fatigue and environmental data necessary to assure a safe, reliable helicopter tension member. For this reason, synthetic rope must be considered only a very weak contender on a short-term basis.

PHASE III

PRELIMINARY DESIGN OF WIRE-ROPE-BELT TENSION MEMBER

The weighted-parameter evaluation technique indicated that the two most promising tension-member candidates are the synthetic tape and the wire-rope belt. Although the synthetic tape placed first in the evaluation, design efforts were directed toward the wire-rope belt concept for several reasons. The high ranking given the synthetic-tape concept assumes that the difficult design problems could be overcome. Also, synthetic tape is the subject of development effort in other programs and will receive major attention in the current Advanced Technology Components Program for the Heavy Lift Helicopter.

Wire-rope belt, on the other hand, appears to have only one significant drawback: it is in the very early stages of development. Although very small wire-rope belts have been fabricated in the past, a major design problem yet to be investigated is the effect of many wraps of a full-size belt wound upon itself under tension. The potential for large compressive forces developing between adjacent wraps is great, but it should be possible to tolerate the high compressive loads with the proper combination of belt construction, encapsulating material, and drum construction.

The preliminary design of a wire-rope-belt tension member to satisfy the requirements of the six load cases must begin with the selection of the rope itself, its size, material and construction, and number of ropes per belt. From this information, the storage drum requirements can be ascertained, as well as details of the drum/belt interface. The required power conductors between the helicopter and the cargo hook should be integrated into the belt construction, if possible, in such a manner that continuity is not affected by normal operation of the tension member. Finally, details of the belt construction, arrangement of ropes, conductors, jacket and encapsulation are problems associated with fabrication of the belt. Once these requirements have been met, the preliminary design of the wire-rope-belt tension member has been determined.

WIRE-ROPE CHARACTERISTICS

Selection of the wire-rope load-carrying elements for the tension member is dictated by several requirements. First, to minimize the overall size of the tension member, wire material of the highest available strength level should be used. Since the encapsulating material of the wire-rope belt will protect the rope wires from moisture and corrosives, it will be possible to use high-strength carbon steel wires rather than one of the corrosion-resistant alloys. Although both types of materials are available at quite high strength levels, research at Battelle has indicated that good wire ductility also is important to the manufacture of wire rope with good fatigue properties. Carbon steel wires offer the best strength and ductility properties of available materials.

The following example illustrates the relationship between the number of ropes per belt and the minimum bend radius for the 6 x 25 filler wire rope. Assuming a ratio of belt thickness (or approximately the rope diameter) to minimum bending diameter of 1:20, typical constructions for the single-point 50-ton load capacity tension member are:

Number of Ropes per Belt	Rope Diameter, inches	Minimum Drum Diameter, inches
2	1-1/4	23-3/4
4	15/16	17-13/16
6	3/4	14-1/4
8	5/8	11-7/8
10	9/16	10-11/16

In other words, for more and more ropes per belt, the minimum drum diameter is reduced proportionately less and less. Considering the increased complexity in fabricating a greater number of ropes into a belt, and the additional drag and flutter problems associated with increased width-to-thickness ratio, the best compromise appears to be either four or six ropes per belt. An even number of ropes is required to provide for a torque-balanced belt construction, with an equal number of right-lay and left-lay ropes utilized. For four ropes per belt, then, the rope diameters for the six load cases are as follows:

Load Case	Rope Diameter, inches
30T-1	11/16
40T-1	13/16
50T-1	15/16
30T-2	9/16
40T-2	11/16
50T-2	3/4

As mentioned above, 20:1 is assumed as the ratio of minimum bend diameter to belt thickness. Since the belt is wound upon itself, this ratio increases until, when the full tape length is retracted upon the drum, the ratio is increased to approximately 50:1, depending upon the belt thickness. It is apparent, therefore, that although the inner few wraps

encounter a severe bending requirement at a 20:1 ratio, the major portion of the belt is not subjected to large bending stresses. In addition, since the several inner wraps are expected to be extended from the drum infrequently, the fatigue life of the entire belt should be quite good.

STORAGE DRUM REQUIREMENTS

The following dimensional analysis of the drum assumes a total belt length of 100 feet and a belt wrap that increases diameter in successive discrete steps (instead of the spiral form which can be anticipated in the actual hoist system). Using this approach, the following relationships may be derived:

$$\ell = n\pi (d_i + nt) \qquad (1)$$

$$d_o = d_i + 2nt \qquad (2)$$

where

ℓ = total belt length, inches

n = number of wraps

d_i = drum inside diameter at hub, inches

t = thickness of belt, inches

d_o = outside diameter of last wrap, inches

A graph of drum inside diameter (d_i) versus the number of tape wraps for a 100-foot tension member is shown in Figure 13 for various belt thicknesses. From this graph and the above equations, the following approximate information is developed for the four-rope belt:

Load Case	Drum Diameter, d_i, inches	Number of Wraps*	Outside Diameter, d_o, inches*
30T-1	13.1	15.9	35.0
40T-1	15.4	14.2	38.5
50T-1	17.8	12.8	41.8
30T-2	10.7	18.3	31.3
40T-2	13.1	15.9	35.0
50T-2	14.3	15.0	36.8

* Based on rope thickness only; thickness of encapsulating material is assumed to be very small.

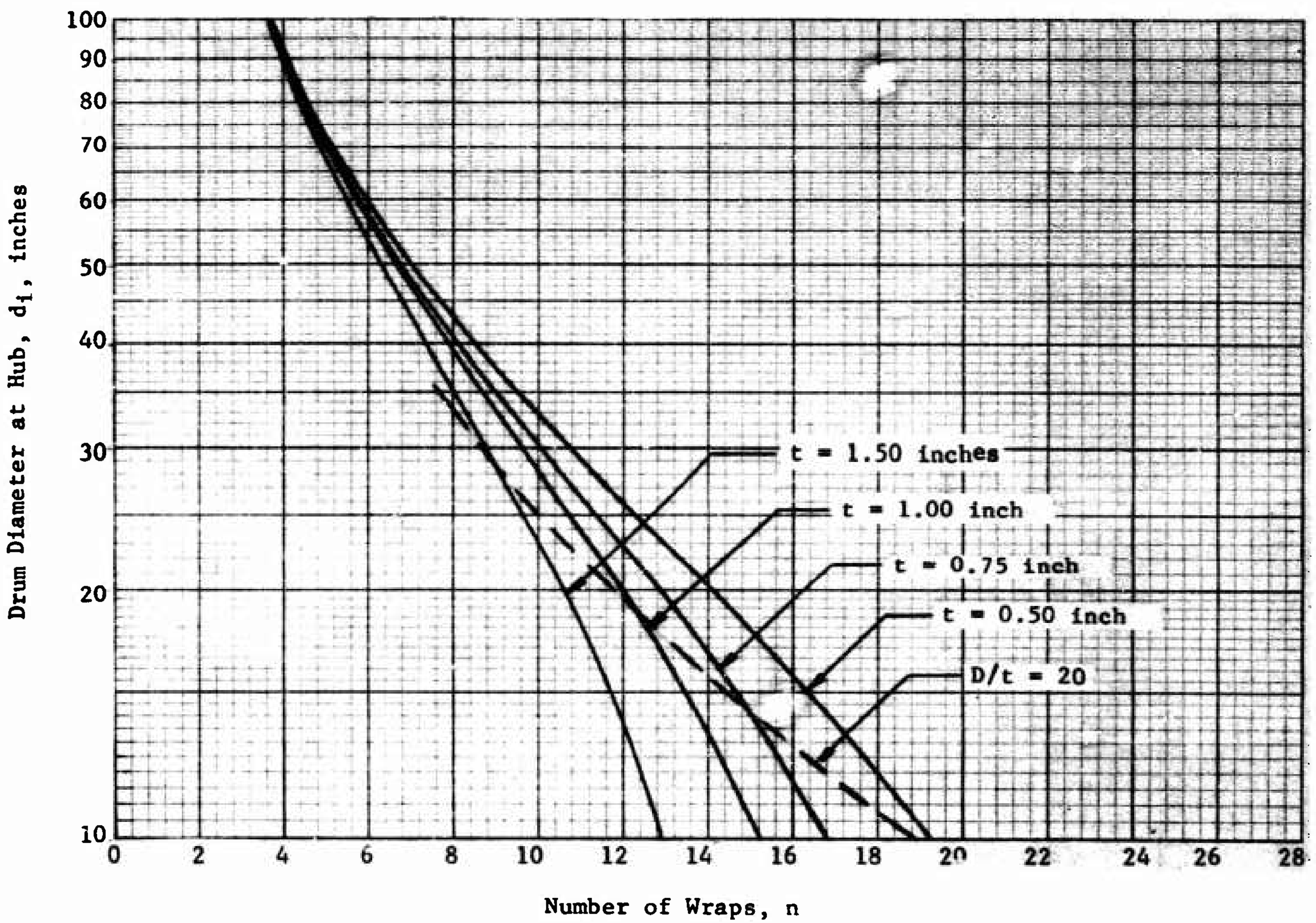


Figure 13. Wire-Rope-Belt Drum Diameter at Hub Versus Number of Wraps.

For this analysis the belt thickness is assumed to be equal to the rope diameter. The small amount of encapsulation material surrounding the ropes is expected to add only an inch or two to the overall outside diameter of the entire tape stack.

It is important to recognize that large compressive or crushing forces will be developed when the belt is wound upon itself on the drum. In the case of a single wrap, the pressure-tension relationship is expressed by

$$p = \frac{T}{rw} \tag{3}$$

where

p = pressure on drum, psi

T = belt tensile load, lb

r = drum radius, inches

w = belt width, inches

For multiple wraps, the pressure developed at the central hub will be somewhat less than the summation of pressures of the individual wraps and will be a potential source of structural problems. The drum flanges must be well gusseted to contain the loads, particularly near the drum hub. One belt design feature that may alleviate this problem of flange loading is the jacket planned for the belt; this jacket may be designed to constrain the lateral expansion of the belt, thereby minimizing the loads on the drum flanges. That this technique may solve the problem is demonstrated by a similar application in the Navy's synthetic tape ground arresting system. The tape in this system undergoes shock loadings and high tensions which force it to slip significantly on the drum and on itself, thus developing high internal pressures similar to, but more severe than, those expected in the helicopter-load tension-member system. The tape has transverse fiber bundles which constrain it from excessive lateral growth. In like manner, the transverse weave in the wire-rope belt jacket should reduce lateral belt expansion and flange loading to an acceptable level.

One further consideration is the outside shape of the belt as it affects the belt-drum interface. To locate each belt wrap directly above the preceding wrap, it is nececessary to make the belt width essentially the same as the distance between the drum flanges. However, some clearance is required to allow lateral expansion of the encapsulation material, or else high flange loads are sure to develop. A possible solution to this problem is to make the belt trapezoidal in shape, giving it "draft", and allowing room for the expansion of the encapsulating material under pressure.

POWER CONDUCTORS

Since existing cargo hooks are actuated electrically, the power conductors for the wire-rope belt probably will be electrical. For simplicity of operation, separate power-conductor reel systems will not be considered; rather, the electrical conductors will be integral with the tension member. The conductors either may be located in the core of the wire ropes, or potted into the encapsulation material between ropes. There are two advantages of the latter technique. First, the present cable on the CH-54 uses a conductor core, and the system has had many instances of broken conductors within the cable, forcing replacement of the entire cable. Second, separate conductors allow the use of the IWRC construction, resulting in smaller diameter ropes for each required breaking strength. A four-rope belt can accommodate six conductors in the voids between the ropes. The space available in these voids allows a conductor (conducting element plus insulation) diameter of one-fourth the wire-rope diameter. This size should be adequate for the electrical requirements of both signal and power transmission to the hook-release solenoid.

The conductor construction must be such that continued compressive and tensile strains may be experienced over the life of the tension member without conductor failure. For the worst case of bending at the drum hub, strains of $\pm$ 5 percent will occur in the belt encapsulating material at the outer surface of the belt. This magnitude of strain suggests that the conductors should be helically wound or woven inside the insulator to allow these strains without breaking from continued fatigue cycling.

BELT FABRICATION

The wire-rope belt will have four strength members in a side-by-side configuration. To constrain the ropes from moving out of alignment, some sort of jacket or sheath is required. This jacket also may be needed to contain a major part of the compression-generated pressures within the encapsulating material. Woven materials of either fine steel wires or synthetic fibers, such as nylon or polyester, are possible candidates. Steel wire mesh, however, would probably not be acceptable due to high cross-wire contact stresses and consequent short life. Therefore, the recommended jacket will be made of synthetic fibers woven to resist lateral strains (widening of the belt under pressure) while allowing the large longitudinal elongations required to accommodate bending of the belt. The jacket might be woven to have fibers in three directions: circumferential, and in two opposite bias weaves. The circumferential fibers should be a straight weave, to minimize elongation under load, while the bias fibers should be woven over and under the circumferential fibers. The choice of fiber material is a function of the desired load-elongation behavior and compatibility with the encapsulation material; nylon is a first choice because of its good adhesion with polyurethane.

The purpose of the encapsulation is twofold: first, a covering is required to protect the wire ropes from the effects of the operational environment; second, the material should hold each rope in place, preventing inter-rope contact and maintaining the belt shape for proper storage on the drum. Several different materials were investigated before cast polyurethane was chosen. Polyurethane has excellent resistance to moisture, ozone, and ultraviolet degradation. Of the elastomer-type materials, it has perhaps the best resistance to abrasion, an important consideration for a belt which is to be wound upon itself. It can be compounded for the required elastic behavior (modulus) and is easily cast in belt shape without the addition of heat or pressure. Successive layers can be built up with proper treatment of the surface to be coated, and polyurethane can be made to adhere permanently to either the wire ropes or the jacket material, or both. The exact compounding of polyurethane ingredients for this application must be selected only after experimental investigation of the compressive stresses between belt layers.

The method of fabricating the belt consists of four distinct steps. First, the four wire ropes and six conductors are positioned in a mold. The mold may be the full belt length, in which case casting can be a single operation. Or the mold may be a short section, in which case the casting operation must be accomplished in several successive steps; the bond between molded belt sections can be made to approach 100 percent of the strength of the polyurethane material. Second, the polyurethane material is poured into the mold and allowed to cure. This operation requires care since an improper or inadequate cure may result in stress cracks in the material, permitting moisture and foreign material to cause corrosion and wear of the wire ropes. The fully cured inner belt is removed from the mold in the third step, and the synthetic fiber jacket is woven tightly around the coating. It is probably more convenient to weave the fibers directly upon the belt, rather than weave them as a separate jacket and then slide the jacket over the belt. Fourth, the belt is placed in a second, slightly larger mold and an outer coating of polyurethane is applied. Again, the curing is most important to prevent stress cracking.

PRELIMINARY DESIGN OF WIRE-ROPE-BELT TENSION MEMBER

The preliminary designs for wire-rope-belt tension members are illustrated in Figures 14 and 15, and are summarized in Table X.

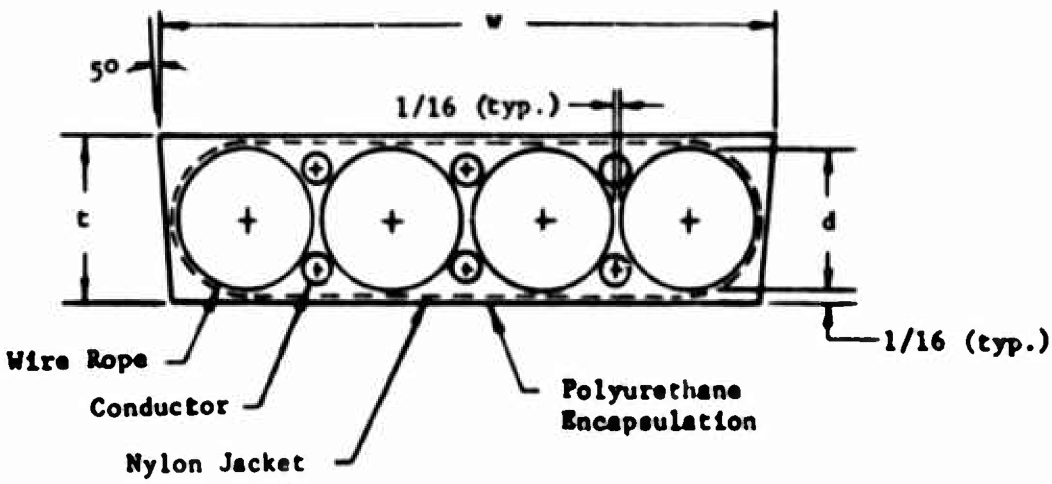


Figure 14. Wire-Rope-Belt Cross Section.

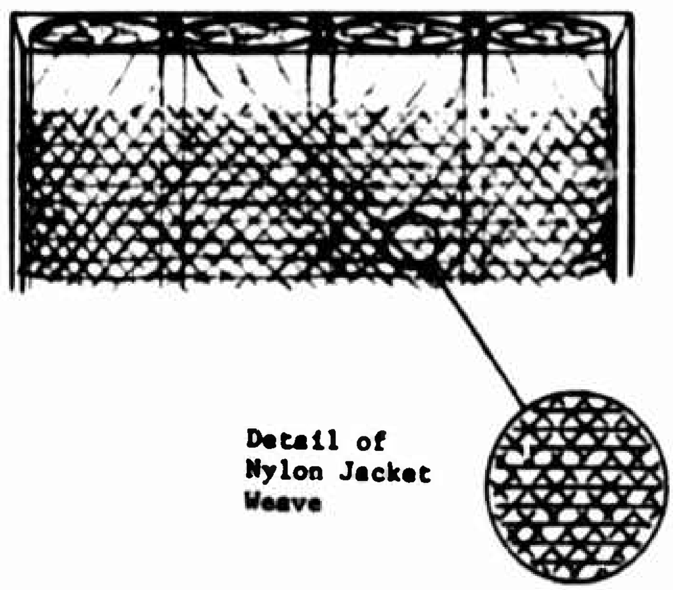


Figure 15. Wire-Rope-Belt Side View.

TABLE X. WIRE-ROPE-BELT PRELIMINARY DESIGN DATA

Wire Material	325,000 psi extra improved plow steel
Wire Construction	6 x 19 class, 6 x 25 filler wire with IWRC
Factory Lubricated	Yes
Number of Wire Ropes	Four
Number of Conductors	Six
Type of Conductors	Insulated, helically wound or woven copper to accept approximately 5 percent elongation
Encapsulating Material	Polyurethane, compounded to resist moisture, grease, ultraviolet radiation, ozone, and abrasion
Jacket Material	Nylon, continuous weave
Fiber Direction	Circumferential, plus 45-degree double-bias

* * * * * * *

	Load Case					
	30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Wire Rope Diameter, inches (d)	11/16	13/16	15/16	9/16	11/16	3/4
Maximum Conductor Diameter, inches*	11/64	13/64	15/64	9/64	11/64	3/16
Belt Width, inches (w)	3-1/8	3-5/8	4-3/16	2-5/8	3-1/8	3-3/8
Belt Thickness, inches (t)	13/16	15/16	1-1/16	11/16	13/16	7/8
Drum Diameter, inches (d_i)	13.1	15.4	17.8	10.7	13.1	14.3
Number of Wraps**	16	14	13	17	16	14
Outside Diameter, inches (d_o)**	39.3	40.9	44.8	34.2	39.3	39.3

*Includes insulation.

**Approximate.

CONCLUSIONS

The weighted-parameter technique developed in Phase I was used for the concept evaluation. In this approach, important physical and operational tension-member parameters were identified and weighted according to their relative importance. Twenty parameters were used. Then each tension-member concept was evaluated with regard to each parameter. The parameter weight and concept evaluation were then multiplied and the products summed to arrive at a final score for each tension-member concept.

An initial discussion of practical considerations was used to evaluate the tension-member concepts for a 1980, or nine-year, time frame. Following this, the concepts were evaluated with respect to 1975 and 1972 time frames. These evaluations considered the concepts first with regard to the results of the weighted-parameter analysis, then from the standpoint of developmental risks. Three concepts (steel tape, roller chain, and jointed links) were deemed unacceptable for any time frame due to overriding technological limitations. The remaining four concepts were analyzed and ranked, and the results are illustrated in Figure 16. The analysis included discussion of developmental risks, materials and costs, fatigue life trade-offs, and technological assumptions.

Because synthetic tape is the subject of development efforts in other programs, the wire-rope-belt concept was chosen for study during the preliminary design phase of this program. The only serious design problem anticipated for this concept is the effect of high compressive loads resulting from the belt being wound upon itself under tension. It should be possible to minimize this problem with the proper choice of belt design and construction, and drum configuration.

Preliminary designs for wire-rope-belt tension members for the six load cases were developed during Phase III of the program. These designs consist of four 6 x 25 filler wire (IWRC) ropes laid side-by-side and wrapped with a nylon fiber jacket. The nylon fibers are aligned circumferentially and on a 45-degree bias to maintain the rope spacing. The entire belt is encapsulated with a cast polyurethane material to protect the ropes from corrosion, abrasion, and intrusion of foreign matter. A unique feature of the design is the trapezoidal belt shape which allows the belt to expand laterally slightly to relieve compressive stresses, while at the same time positioning each wrap directly over the previous one on the storage drum. Electrical conductors for hook actuation are located in the voids between ropes and are held in place by the encapsulating material.

Acceptable Helicopter Tension-Member Concepts, in Order of Decreasing Feasibility:

<u>1972</u>

1. Wire Rope
2. Synthetic Rope

<u>Interim Development Effort</u>

Tape or Belt Drive Hoist

Synthetic Fibers

Wire Materials

<u>1975</u>

1. Wire-Rope Belt
2. Synthetic Tape
3. Wire Rope
4. Synthetic Rope

<u>Interim Development Effort</u>

Synthetic Fibers

Wire Materials

<u>1980</u>

1. Synthetic Tape
2. Wire-Rope Belt
3. Synthetic Rope
4. Wire Rope

Figure 16. Tension-Member Concepts for 1972, 1975, and 1980 Time Frames.

RECOMMENDATIONS

For the purpose of advancing the state of the art of helicopter-load tension-member technology, Battelle recommends developmental work in these three general areas:

Tape- or Belt-Drive Tension-Member Hoists

Tension-Member Materials

Tension-Member Constructions

To simplify the hoist-drive package for the tension member, Battelle recommends the development of a functional, tape-drive hoist. The development effort should begin with the technology available from the U. S. Navy's tape-arrestment system. An analysis can be made of the power requirements necessary due to the torque changes from varying the drive radius. Tape crushing loads can be investigated to provide a basis for tension-member material selection and construction.

Continued development of both wire materials and synthetic fibers is recommended. It appears likely that synthetic-fiber rope or tape will, in time, replace wire-rope-based constructions as the most feasible candidates for helicopter tension members. The development by du Pont of the proprietary fiber PRD-49 is an indication of the strengths and moduli which can be achieved while still retaining the desirable properties of the synthetics. These advances, however, though significant, are not grounds for discontinuing the development of ever stronger and more ductile wire materials for ropes.

To develop the wire-rope-belt tension-member concept, Battelle recommends that an investigation be undertaken of the many design variables that influence the belt characteristics. This investigation should be primarily experimental in nature, involving the testing of full-size belt samples of varying construction. Four categories of variables are identified below, with recommended items for investigation:

(1) Construction of load-carrying elements:

(a) 6 x 25 filler wire with IWRC (12 outer wires per strand)

(b) 6 x 41 Warrington-Seale (16 outer wires per strand)

(c) Special short-lay 49-wire strand

(2) Polyurethane encapsulating materials of several different elastic moduli, all compounded for resistance to abrasion, ultraviolet radiation, grease, moisture, and ozone

(3) Jacket materials including nylon, nylon-polyester, and polyester

(4) Belt construction variables including rope spacing, thickness of outer cover, and shape of the belt edges

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APPENDIX I

MATRIX COMBINATIONS FOR TASKS A AND B

A review of the pertinent parametric interactions in the Tasks A and B matrix resulted in the following explanations and comments.

LOAD CAPACITY/FATIGUE LIFE

The fatigue life of a tension member is dependent on the frequency of loading and percentage of load capacity to which it is subjected.

LOAD CAPACITY/SHOCK LOADING

The shock load resistance of a tension member depends largely on its elastic modulus. Shock loading is a concern when the payload approaches the load capacity of the tension member.

LOAD CAPACITY/ENVIRONMENTAL EFFECTS

The load capacity of a tension member may be reduced by the environmental effects of temperature, humidity, contamination, and solar radiation.

LOAD CAPACITY/INSPECTION

It is highly desirable that the tension member be inspectable for evaluating any deterioration which might reduce the load capacity.

LOAD CAPACITY/SAFETY

The operational safety of a tension member depends on the correct application of loading. The load capacity of the member may be exceeded by intentional overloading or by shock-induced overloads which can exceed the yield strength of the member without warning to the operator.

LOAD CAPACITY/USEFUL LIFE

If a tension member is operated at or near its load capacity most of the time, the useful life may be substantially less than if it is operated under moderate loads.

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LOAD CAPACITY/DRIVING POWER

The driving power of a hoisting system may be large enough to exceed the ultimate breaking strength of the tension member. This excess power may cause overstress or yielding of the member in service. A slip-clutch may be used in the power drive train to eliminate this overload possibility.

LOAD CAPACITY/CONE ANGLE

The tensile stress in the tension member will increase as the cone angle increases (as when the attachment points on the load are spaced differently from those on the aircraft).

LOAD CAPACITY/LOAD ACQUISITION

The required load capacity of the tension member may be influenced by problems encountered during load acquisition, such as lifting the maximum design payload from muddy terrain.

LOAD CAPACITY/THERMAL EFFECTS

If the heat buildup in the tension member due to rubbing against itself or other parts of the system is high enough, the load capacity of the member may be degraded. Two examples are the phase change in wire-rope steel wires (to martensite) and the fusing of synthetic rope strands with subsequent loss in strength.

LOAD CAPACITY/STRENGTH

The required breaking strength of the tension member is determined by multiplying the desired load capacity by the required safety factor, the gust load factor, and, for the multipoint system, the cone-angle factor and the center-of-gravity factor.

LOAD CAPACITY/WEAR

Reduction in tension-member cross section due to wear will reduce its ultimate breaking strength and, therefore, its load capacity.

LOAD CAPACITY/NATURAL FREQUENCY

The design of the tension member should be such that its natural frequency is well removed from that of any forcing vibrations (such as

rotor blade frequency). This constraint is due to the high amplitudes of resonant vibrations which may occur, resulting in high overloads, flight instability, and rapid accumulation of fatigue cycles.

LOAD CAPACITY/TORSIONAL CHARACTERISTICS

Several tension-member concepts, such as wire ropes and multistranded flat belts, may experience a loss in load capacity under torsion. This is due to a part of the tension member unloading when twisted, putting the entire load on a reduced cross section and thus lowering the load capacity.

LOAD CAPACITY/WEIGHT

One of the prime considerations for a tension member is to design the highest load capacity for the least system weight. See also Strength/Weight.

LOAD CAPACITY/END CONNECTIONS

The tension-member end connections may be the weakest part of the system. These connections must be designed to the required load capacity, taking into consideration its influence on tension-member strength; high induced stresses in the tension member at the end connections must not reduce the effective load capacity of the system.

FATIGUE LIFE/SHOCK LOADING

Shock loading may appreciably shorten the fatigue life of a tension member.

FATIGUE LIFE/STORAGE

The storage of a tension member will require careful attention to the number of bends and the bend radii to prevent fatigue from repeated high bending stresses.

FATIGUE LIFE/ENVIRONMENTAL EFFECTS

The environment in which the tension member operates may well determine its resistance to fatigue damage. Embrittlement due to low temperatures or surface damage due to contamination or corrosion may accelerate fatigue deterioration.

FATIGUE LIFE/SAFETY

The fatigue characteristics of the tension member must be well understood to assure an adequate factor of safety for the system.

FATIGUE LIFE/DUTY CYCLE

The loads encountered during the duty cycle of a tension member will have a direct effect on the fatigue life of a tension member. It is necessary to consider the entire loading spectrum as it affects fatigue life; both high-frequency, low-magnitude loads and low-frequency, high-magnitude loads are important.

FATIGUE LIFE/USEFUL LIFE

The useful life of a tension member can be extended by proper design and attention to the fatigue inputs to the member.

FATIGUE LIFE/FLIGHT STABILITY

Good flight stability of a tension member may increase the fatigue life of the member. Large vertical or lateral oscillations during flight may rapidly accumulate stress cycles which may ultimately produce fatigue failure of the tension member.

FATIGUE LIFE/LOAD STABILITY

Good load stability may increase the fatigue life of a tension member by reducing the amplitude of the tension variations in the member.

FATIGUE LIFE/CONE ANGLE

The cone angle determines the required bending of the tension member upon extension from the aircraft. The resulting bending stresses must be considered in determining the fatigue life.

FATIGUE LIFE/THERMAL EFFECTS

See Load Capacity/Thermal Effects. Not only will phase changes in the tension-member material, brought on by excessive heat buildup, usually lower the load capacity, but cracks may be produced that will propagate quickly and thus greatly reduce the fatigue life.

FATIGUE LIFE/WEAR

Fatigue damage depends not only on the number of load cycles, but also on the percentage of ultimate strength reached during each cycle. Wear that significantly reduces the load-bearing area of the tension member will increase this percentage and reduce the tension-member fatigue life. Also, wear may produce stress concentrations at surface irregularities and, thereby, promote fatigue crack formation.

FATIGUE LIFE/FLEXIBILITY

The more flexible the tension member, the greater its bending fatigue life due to lower bending stresses in the outer elements. The directional aspects of some tension member concepts may require intermediate cross-axis links to provide greater flexibility (e.g., chain-type concepts).

FATIGUE LIFE/NATURAL FREQUENCY

If the tension member experiences forced vibrations near its natural frequency, it may oscillate harmonically, thus adding many more load cycles to its fatigue history. The resulting cumulative damage may severely shorten the fatigue life.

FATIGUE LIFE/DAMPING

Generally, the greater the damping, the longer the fatigue life. Damping reduces both the magnitude and number of load cycles on the tension member after an initial disturbing force.

FATIGUE LIFE/TORSIONAL CHARACTERISTICS

The fatigue life of the tension member may be significantly reduced if the tension member twists under load. The resulting internal and/or external wear on the surfaces moving under high unit loading may induce notching or fatigue cracking, raising the stresses and reducing the life.

FATIGUE LIFE/STATE OF DEVELOPMENT

It may be possible to consider some tension-member concepts which have not yet been used operationally if their fatigue life can be relied upon analytically.

FATIGUE LIFE/KINK RESISTANCE

Kink resistance designed into the tension member should improve its fatigue life by reducing the number and magnitude of adverse (fatigue crack-producing) bending cycles.

FATIGUE LIFE/ABRASION RESISTANCE

The fatigue life of the tension member may be directly affected by its ability to resist fatigue-crack-producing abrasive wear.

FATIGUE LIFE/END CONNECTIONS

The end connections of a tension member must be designed with careful attention given to elimination of fatigue-crack-producing stress concentrations.

FATIGUE LIFE/MINIMUM BEND RADIUS

The fatigue life of the tension member will be directly affected by the minimum bend radius it experiences during operation. This is true because the bending stresses produced are added to the tensile stresses, and fatigue damage is proportional to both number of cycles and stress magnitude.

FATIGUE LIFE/REVERSE BENDING

Reverse bending of the tension member may greatly shorten the fatigue life, since the resulting range of stress from maximum to minimum will be larger than would be experienced without reverse bending.

FATIGUE LIFE/FLEET ANGLE

Care must be taken that an excessive fleet angle does not produce stress-raising cracks due to interelement scuffing, as this will greatly reduce fatigue life in the tension member. See also Minimum Bend Radius/Fleet Angle.

SHOCK LOADING/SAFETY

The operational safety of a tension member depends on the correct application of loading. The load capacity of the member may be exceeded by intentional overloading or by shock-induced overloads which can exceed the yield strength of the member without warning to the operator.

SHOCK LOADING/USEFUL LIFE

The useful life of the tension member may be substantially reduced by fatigue-producing shock loads.

SHOCK LOADING/SPEED

The speed of the tension member will influence the shock loading because of the starting and stopping characteristics of the hoist system. A sudden speed change could cause inertia overloading of the member.

SHOCK LOADING/LOAD ACQUISITION

Acquisition of the load in a manner that will jerk the tension member, as in rapid take-up of a slack member, may produce severe shock loading.

SHOCK LOADING/LOAD RELEASE

Stored elastic energy in the tension member, coupled with premature release of a load, may shock load the member or snap it up into the aircraft or rotor blades. Release of a load with tension in the member may cause backlash or "bird caging" of the tension member in the hoisting mechanism.

SHOCK LOADING/RELIABILITY

A tension member which has good shock load resistance should be inherently more reliable.

SHOCK LOADING/THERMAL EFFECTS

Normal load-unload cycling to rated capacity should not produce excessive heat buildup in the tension-member material. However, shock loading can produce high rubbing velocities and virtually instantaneous heat buildup which may not be dissipated quickly enough to prevent phase changes or other undesirable thermal damage.

SHOCK LOADING/STRENGTH

When the tension member is being operated at its load capacity, there should remain enough strength to allow the maximum expected shock loads to be experienced without failure or serious damage.

SHOCK LOADING/WEAR

Shock loading can produce internal wear not normally encountered in moderate service, and also external wear if the tension member rubs on a rough surface under high shock loads. Localized wear such as this can produce localized stress raisers which may cause premature failure.

SHOCK LOADING/ELASTICITY

The shock loading experienced by a tension member will be most severe when a short length is extended and the member has low elasticity.

SHOCK LOADING/DAMPING

In the event that a shock load is experienced by one end of the tension member, some means of damping at the other end will assure that the shock wave is not reflected. This would probably eliminate the problem of "reinforcement" of shock load waves.

SHOCK LOADING/KINK RESISTANCE

Shock loading (or unloading) may produce a kink of unacceptably small bend radius, resulting in yielding and possibly failure of the tension member material. A tension member with good kink resistance is required to prevent this form of damage.

SHOCK LOADING/ABRASION RESISTANCE

Shock loading can produce high unit pressure and sliding velocities between elements within the tension member or between the tension member and adjacent hardware. Since shock loading may be expected to occur, the tension member must be able to resist possible resultant abrasion.

SHOCK LOADING/FRICTION OR TRACTION DRIVE

The design of a friction drive must accommodate the shock overloads as well as the static and driving loads of the tension member.

STORAGE/ENVIRONMENTAL EFFECTS

Detrimental environmental effects on the tension member during storage should be minimized. Isolation from aircraft-produced conditions

(heat, vibration, downwash, etc.) may be as important as isolation from external effects.

STORAGE/INSPECTION

A tension member should be designed to allow inspection for abrasion, wear, or deterioration while it is in the stored position. It is undesirable to require the tension member to be extended to its full length for inspection.

STORAGE/SAFETY

The tension member may be stored while still retaining considerable strain energy. When disconnecting the member for maintenance, care must be taken to prevent injury to personnel or damage to surrounding equipment.

STORAGE/USEFUL LIFE

The useful life of a tension member may be extended if care is exercised in the proper storage of the member.

STORAGE/DRIVING POWER

The driving power required for a hoist system must be adequate for storage and may vary considerably, depending upon the storage design. For example, a tension member reeled upon itself would require an increasing torque input to maintain speed.

STORAGE/SPEED

The speed of the tension member may be limited by the storage system. For instance, some level-wind systems require slower operation than others. Also, the size of a storage drum may influence its starting and stopping characteristics and, therefore, the speed of the system.

STORAGE/POWER CONDUCTORS

The signal or power for the hook will require consideration for the storage and termination of the power conductors whether they are separate or integral with the tension member.

STORAGE/MAINTENANCE

Convenient tension-member maintenance requires that the member be stored in an accessible manner both for installation and inspection. The replacement time for a damaged tension member must be kept to a minimum.

STORAGE/SUSCEPTIBILITY TO GUNFIRE

Proper storage of the tension member should incorporate adequate protection from enemy fire.

STORAGE/THERMAL EFFECTS

The means of storing the tension member must be such that friction, rubbing, or working of the member under load does not induce damaging heat buildup.

STORAGE/SHAPE

The type of storage required for a tension member varies with the tension-member shape. A round cross section can be stored by helical-winding on a drum. Flat-belt or roller-chain tension members must be wound layer on layer or stored by racking or in bins.

STORAGE/WEAR

Care must be exercised in the design of both the tension member and the means of storage to preclude excessive wear. This is a consideration both when the member is passing in or out of storage and when it is stationary in storage (as on a drum or in a bin).

STORAGE/FLEXIBILITY

In general, the less flexible the tension member, the more difficult will be its storage. For example, a very stiff wire rope will require a much larger diameter storage drum than a flexible synthetic rope.

STORAGE/ELASTICITY

If the tension member is to be stored under tension, provision must be made for storing the extra length of the member due to the resulting elastic deflection (elongation).

STORAGE/STORED ENERGY

Provision may be required in the hoist system to isolate the extended part of the tension member from the storage area to assure that sudden load release under tension and the resulting "snapback" does not cause kinking, unraveling, or unspooling. This problem is of particular concern for a highly elastic tension member. See also Maintenance/Stored Energy.

STORAGE/TORSIONAL CHARACTERISTICS

If the tension-member design is such that it twists when the load is applied or removed, care should be taken in the design of the storage elements. When the tension member twists under low back-tension, as when coming off a friction drive, scuffing of the member on the storage elements must be minimized. See also Safety/Torsional Characteristics.

STORAGE/ANTIROTATION

Antirotation alleviates some of the torsional problems associated with storing an elastic tension member. See Storage/Torsional Characteristics.

STORAGE/STATE OF DEVELOPMENT

Some storage concepts, such as level-wind drums, have been developed to the point where design for the heavy-lift hoist application is just an extension of present knowledge. Other means, such as racking or open-bin storage, must be designed and developed to fit the need.

STORAGE/WEIGHT

It may be possible to reduce the weight of the storage elements by proper consideration of the tension-member design (e.g., utilization of bin storage or new drumless winch concepts).

STORAGE/KINK RESISTANCE

If the tension member is properly designed, it will resist kinking when passing from the high tension loaded side of a traction drive to the low back-tension of the storage. Otherwise, the storage element must provide enough back-tension to prevent kinking. See also Storage/Torsional Characteristics.

STORAGE/END CONNECTIONS

The storage must be designed to accommodate whatever type of connection is required on the aircraft end of the tension member. It may be that this connection must not only carry a significant part of the load, but also allow attachment of power conductors. (Presently used cables have breakage problems with the electrical wire connections at the drum end.)

STORAGE/MINIMUM BEND RADIUS

The size and shape of the tension member storage hardware is likely to be dependent upon the minimum bend radius the member may experience. As with a rope or cable reeled on a drum, the larger the allowable bend radius, the larger the storage drum.

STORAGE/REVERSE BENDING

Although storage may be accomplished under minimum load conditions, the existence of reverse bending will nonetheless induce fatigue-producing stresses in the tension member.

STORAGE/FLEET ANGLE

It may be possible to design the tension-member storage hardware to minimize the fleet angle; this may lead to weight, space, and cost penalties as with a level-wind system.

ENVIRONMENTAL EFFECTS/INSPECTION

The design of the tension member should be such that it can be readily inspected by simple inspection techniques for environmental deterioration.

ENVIRONMENTAL EFFECTS/USEFUL LIFE

The useful life of a tension member may be shortened if the member is not protected or designed to exclude the effects of its environment such as corrosion and temperature-induced cracking.

ENVIRONMENTAL EFFECTS/POWER CONDUCTORS

The effects of sand, dust, moisture, or corrosion must not cause loss of signal and/or power to the hook. (Currently, slip rings at the hook-cable interface malfunction due to environmental corrosion.)

ENVIRONMENTAL EFFECTS/STRENGTH

Heat, moisture, and other environmental factors can reduce the strength of the tension member; this fact must be considered in the design.

ENVIRONMENTAL EFFECTS/SHAPE

The shape of the tension member may be designed to prohibit the entrance of moisture and foreign material, thus eliminating the chances of internal wear and corrosion.

ENVIRONMENTAL EFFECTS/WEAR

If the tension member is to be used in a hostile environment (blowing sand, high heat, and humidity), it may be necessary to provide it with some external protective coating to minimize damage to the load-carrying material. See also Environmental Effects/Shape.

ENVIRONMENTAL EFFECTS/NATURAL FREQUENCY

If the environment encountered by the tension member includes vibratory frequencies at or near its natural frequencies (rotor blade frequency, engine vibrations, etc.), both immediate and long-term damage may result. See Load Capacity/Natural Frequency and Fatigue Life/Natural Frequency.

ENVIRONMENTAL EFFECTS/DAMPING

Mounting of the hoist drive, storage, and tension member to the helicopter airframe with damping material or devices should help isolate the system from detrimental engine or rotor vibrations.

ENVIRONMENTAL EFFECTS/ABRASION RESISTANCE

The tension member must be able to resist the abrasive effects of its operating environment, such as blowing sand and dirt. This may be accomplished either by covering the tension member with a protective coating or by hardening its surface.

ENVIRONMENTAL EFFECTS/FRICTION OR TRACTION DRIVE

The environmental effects of dust, dirt, sand and moisture must not affect the friction characteristics of the tension member to the point where normal operation is impossible.

relation to the amount of exposed surface area. A flat-belt type of construction will be simpler to inspect visually than a round or rectangular thick section.

INSPECTION/WEAR

A tension member should be inspectable for wear, preferably both visually (external) and with nondestructive techniques (internal).

INSPECTION/STATE OF DEVELOPMENT

Helicopter tension members (cables) are now inspected visually for damage. It may be possible in the future to utilize some means of detecting damage automatically such as with x-rays or some other nondestructive technique.

SAFETY/EASE OF GUILLOTINING

The safety of the entire aircraft and crew may often depend on the ability to quickly jettison the load and tension member under emergency conditions. Simultaneous guillotining ability is a safety requirement when a load is suspended in a multipoint configuration.

SAFETY/POWER CONDUCTORS

Redundancy in the power-conductor system is a requirement to assure the safe, remote operation of the load acquisition hook.

SAFETY/STATIC ELECTRICITY

Some means must be provided to prevent personnel hazard due to static electricity discharge from the hook or tension member during load acquisition. This function may be accomplished by either continuous grounding or by insulation by means of a nonconducting element in the hoist system.

SAFETY/LOAD ACQUISITION

Personnel safety during load acquisition is concerned with control of the tension member. Vertical control is necessary to assure that the hook is not "dropped" on either the load or ground personnel. Horizontal control is necessary to assure that the inertia of a moving hook and tension member does not create a hazard.

ENVIRONMENTAL EFFECTS/POSITIVE DRIVE

A hostile environment must not affect the tension member in such a way that the indexing or level winding of a positive drive is forced out of synchronization.

ENVIRONMENTAL EFFECTS/END CONNECTIONS

The hook and exposed end fittings must be designed so that dirt and moisture cannot become entrapped, causing internal corrosion and malfunction.

INSPECTION/SAFETY

Safety in operation of the tension member will depend on the timely determination of possible damage through frequent inspection.

INSPECTION/USEFUL LIFE

The useful life of a tension member may be extended by corrective action following inspection of the member. Useful life may be shortened if inspection is difficult and damage to the tension member remains undetected.

INSPECTION/POWER CONDUCTORS

It is highly desirable that routine inspection procedures of the tension member include a convenient technique for determining the condition of the power conducting elements.

INSPECTION/RELIABILITY

The reliability of the tension member is directly proportional to the ease of inspection.

INSPECTION/STRENGTH

It must be possible to inspect the tension member to discover any damage or deterioration which might affect its strength.

INSPECTION/SHAPE

The shape of the tension member influences its inspectability in direct

SAFETY/LOAD RELEASE

It is desirable that upon load release, the tension member have a low stored energy. This implies a low tension or slack condition so that there is no danger of a snap-back damaging aircraft fuselage or rotor blades or injuring personnel.

SAFETY/EASE OF HANDLING

It is desirable that the tension member be flexible so that during load acquisition the hook may be moved into place directly over the load by ground personnel without undue effort.

SAFETY/THERMAL EFFECTS

Safe use of the tension member assumes not only that every design effort is made to preclude damage due to heat buildup, but also that periodic inspection will reveal such damage if it occurs prior to its becoming a safety hazard.

SAFETY/SHAPE

A tension member with sharp edges or projections should be avoided in consideration of personnel safety.

SAFETY/ELASTICITY

See Maintenance/Elasticity.

SAFETY/NATURAL FREQUENCY

The harmonic oscillation of the load/tension-member/aircraft system can severely affect the pilot's ability to control the aircraft. Evidence of this is found in the "vertical bounce" phenomenon; because of the pilot's location with respect to the load and the aircraft center of gravity, his control inputs may be out of phase with the induced oscillation, thus increasing the amplitude rather than cancelling it out.

SAFETY/STORED ENERGY

The safety of the hoist system requires that the design protect both the aircraft and the flight crew from the effects of stored energy in the tension member. Release of a load under tension or failure of a

loaded tension member may cause the tension member to whip up into the helicopter rotor blades or the belly of the fuselage, severely endangering the entire man-machine system.

SAFETY/TORSIONAL CHARACTERISTICS

Retention of torsional energy when the tension member is stored under load necessitates extreme care in extending the member, either with or without a load attached. In the first case, the load may tend to spin, although this tendency may be reduced by attaching the hook through a swivel. In the second case, the tension member may twist, swing, or kink, endangering personnel nearby.

SAFETY/ANTIROTATION

Antirotation built into the tension member will keep the hook from rotating and endangering ground personnel. Also, antirotation will make the handling of a stored tension member safer, reducing the possibility of stored torsional energy.

SAFETY/KINK RESISTANCE

Kink resistance should reduce the possibility of inadvertent tension member failure. See also Shock Loading/Kink Resistance.

SAFETY/ABRASION RESISTANCE

The safety of the tension member will be improved in two ways with the proper abrasion-resistant design. First, excessive wear will be eliminated, avoiding premature failure due to reduced cross-sectional area. Second, the likelihood of abrasion-caused stress-raising cracks will be reduced.

SAFETY/END CONNECTIONS

The safety of the entire tension member system depends upon the proper design of the end connections (1) to allow the transmission of power to operate the hook-release mechanism and (2) to accept all anticipated operational loads without premature failure.

DUTY CYCLE/LOAD ACQUISITION

The duty cycle is influenced by the time required to acquire a load. The man-to-hook relationships must be carefully considered to obtain the most efficient system.

DUTY CYCLE/NATURAL FREQUENCY

Any evidence of resonance of the load and tension member, either during flight or when picking up or releasing a load, will probably cause the pilot to spend extra time stabilizing the system, thus lengthening the duty cycle.

USEFUL LIFE/FLIGHT STABILITY

Good flight stability of a tension member may increase the fatigue life of the member. Vertical or lateral oscillation during flight may rapidly accumulate stress cycles which may ultimately produce fatigue failure of the tension member.

USEFUL LIFE/EASE OF HANDLING

The manner in which a tension member is handled is important to its useful life. Every effort must be made to avoid kinking, twisting, or dragging the member against abrasive objects, especially during tension-member replacement.

USEFUL LIFE/MAINTENANCE

The useful life of a tension member may be extended through proper maintenance. Ease of maintenance is necessary to insure that the member lasts the required number of aircraft flight hours.

USEFUL LIFE/SUSCEPTIBILITY TO GUNFIRE

A tension member should be able to survive a hit from enemy gunfire, but the degree of useful life remaining will depend upon the tension-member design. A member having a multiple-element construction should offer the longest life.

USEFUL LIFE/THERMAL EFFECTS

Thermal damage to the tension member material can shorten the fatigue life and reduce the useful life. See Fatigue Life/Thermal Effects.

USEFUL LIFE/WEAR

See Fatigue Life/Wear.

USEFUL LIFE/FLEXIBILITY

See Fatigue Life/Flexibility.

USEFUL LIFE/NATURAL FREQUENCY

See Fatigue Life/Natural Frequency.

USEFUL LIFE/STATE OF DEVELOPMENT

See Fatigue Life/State of Development.

USEFUL LIFE/KINK RESISTANCE

See Fatigue Life/Kink Resistance.

USEFUL LIFE/ABRASION RESISTANCE

See Fatigue Life/Abrasion Resistance.

USEFUL LIFE/END CONNECTIONS

See Fatigue Life/End Connections.

USEFUL LIFE/MINIMUM BEND RADIUS

See Fatigue Life/Minimum Bend Radius.

USEFUL LIFE/REVERSE BENDING

See Fatigue Life/Reverse Bending.

USEFUL LIFE/FLEET ANGLE

See Fatigue Life/Fleet Angle.

FLIGHT STABILITY/LOAD STABILITY

The tension-member flight stability must not be adversely affected by load configurations which affect load stability. Instability of the

tension member should not induce resonant oscillations of the load and vice versa.

FLIGHT STABILITY/CONE ANGLE

The cone-angle requirements of the tension member must not adversely affect its flight stability.

FLIGHT STABILITY/SHAPE

The aerodynamics of a tension member will vary with its shape. For example, a wide flat tension member could produce "flutter" and steering problems as well as high drag. A round or streamlined configuration is more desirable from a drag or flutter standpoint.

FLIGHT STABILITY/FLEXIBILITY

The flight stability of the tension member may be dependent upon its flexibility. The lateral oscillation frequency will depend on tension, mass per unit length, and flexibility; the more flexible the tension member, the lower its lateral natural frequency under aerodynamic loading.

FLIGHT STABILITY/ELASTICITY

The flight stability of a tension member is a function of its shape, tension load, and elastic modulus. The more elastic the member, the more likely it will experience lateral vibration under aerodynamic loading.

FLIGHT STABILITY/NATURAL FREQUENCY

Lateral vibration near the natural frequency of the tension member during flight may become unstable if not properly controlled, either by damping or by change in forcing frequency; unstable tension-member vibration can cause loss of load, tension member, and aircraft due to the rapid accumulation of fatigue cycles or overloading of the tension member.

FLIGHT STABILITY/DAMPING

If the tension-member physical characteristics are such that it has a natural damping tendency, the magnitude of the lateral vibrations induced by aerodynamic forces may be reduced.

FLIGHT STABILITY/TORSIONAL CHARACTERISTICS

The flight stability of the tension member may be improved if it is torsionally stiff so that it does not tend to twist under vertical load fluctuations.

LOAD STABILITY/SPEED

The required tension-member hoisting speed should not affect the load stability characteristics; the tension member should allow a smooth lift of the load.

LOAD STABILITY/LOAD ACQUISITION

The tension member should not affect the stability of the load during the load acquisition phase of operation. The tension-member behavior should not lead to either bouncing or twisting of the load during lift-off.

LOAD STABILITY/ELASTICITY

The more elastic a tension member, the more it will respond to vertical oscillation of the load moving through the air. This could lead to unstable coupled vibration of large amplitude, affecting the aircraft handling.

LOAD STABILITY/NATURAL FREQUENCY

Assuming that the load itself can be made aerodynamically stable (nose-down configuration, etc.), the combination of load and tension member must be examined to ascertain that no forcing vibrations are encountered during operation at or near the system's natural frequency. This determination will assure that the load stability is not adversely affected by the tension member elasticity.

LOAD STABILITY/DAMPING

An elastic tension member should be damped in the vertical mode to reduce oscillations which might adversely affect the stability of the suspended load.

LOAD STABILITY/TORSIONAL CHARACTERISTICS

A swivel at the cargo hook probably will be required to prevent load

rotation from damaging the tension member, especially with the single-point suspension.

LOAD STABILITY/ANTIROTATION

Antirotation in a tension member should help prevent the load from spinning during pickup.

LOAD STABILITY/END CONNECTIONS

Unless the tension member is antirotative, a swivel or other uncoupling device should be designed into the lower end connection to minimize the interactions of the tension member and load stability.

DRIVING POWER/SPEED

The driving power must increase as the speed of the tension member increases. It is therefore appropriate to consider a lowering of the speed when the load is high to maintain a reasonable power demand.

SPEED/POWER CONDUCTORS

Operation of the tension member at maximum speeds should not affect either the quality of the signal or the life of the conductors.

SPEED/LOAD ACQUISITION

Initial load lift-off should be accomplished at a low speed to avoid high inertia loads on the tension member.

SPEED/EASE OF HANDLING

The tension-member speed must be controlled to slow the hook as it approaches the load so that the loading crew will be able to guide the attachment hardware onto the hook.

EASE OF GUILLOTINING/SHAPE

Generally, the thinner the tension member in the direction of guillotine movement, the easier it will be to cut the member in an emergency situation.

EASE OF GUILLOTINING/ABRASION RESISTANCE

The ease with which a tension member may be cut in an emergency may be reduced if the requirements of abrasion resistance necessitate a very hard surface on the member.

CONE ANGLE/LOAD ACQUISITION

The load-acquisition method must not impose an unacceptably high cone angle on the tension member.

CONE ANGLE/THERMAL EFFECTS

If the cone angle of the tension member creates rubbing upon the lead-in hardware, it may be necessary to alleviate the friction and/or bending loads to minimize heat buildup.

CONE ANGLE/STRENGTH

For a given load capacity, the ultimate breaking strength of the tension member must be increased with increased cone angle (by the inverse of the cosine of the cone angle).

CONE ANGLE/SHAPE

If the tension-member shape is such that it bends more easily in one direction than another, the maximum allowable cone angle may be greater in the direction of easier bending unless the winch or fairlead hardware is mounted in gimbals.

CONE ANGLE/WEAR

Generally, the greater the cone angle, the greater the wear of the tension member at the exit point of the hoist system. If an exit cone or funnel is used as a guide for the tension member, it may cause abrasive wear and high bearing loads.

CONE ANGLE/FLEXIBILITY

The more flexible the tension member, the more easily it will accommodate the required maximum cone angle. If the member is too stiff to reach the required cone angle without unacceptable bending stresses, the winch or fairlead might require gimbals.

CONE ANGLE/STORED ENERGY

The greater the cone angle, the greater the stored energy in a tension member, due to the greater tension and elongation.

CONE ANGLE/ABRASION RESISTANCE

Unless the tension member can be extended and retracted directly at the required cone angle, some sort of lead-in funnel may be required. The tension member must then be designed to resist the abrasion caused by rubbing on the funnel.

CONE ANGLE/FLEET ANGLE

A lead-in cone to the hoist system may be necessary to prevent the desired cone angle from producing an unacceptable fleet angle.

POWER CONDUCTORS/STATIC ELECTRICITY

Static electricity discharge must not inadvertently actuate the hook release or prevent a signal from performing its proper function.

POWER CONDUCTORS/LOAD RELEASE

Power conductors are required for remote actuation of the hook during load release.

POWER CONDUCTORS/RELIABILITY

The reliability of the power conductors should equal or exeed the reliability of the tension member to ensure a useable system.

POWER CONDUCTORS/SUSCEPTIBILITY TO GUNFIRE

Survivability of the power conductors is generally enhanced by making them integral with the tension member.

POWER CONDUCTORS/SHAPE

The shape of the tension member will influence the placement of integral power conductors used for actuating the cargo hook. A round cross section will allow the use of centrally located power conductors (such as in the present electromechanical cable), while a flat member must

have its power conductors nearer the surface. The latter design has the advantage of ease of power-conductor inspection, and the disadvantage of exposure of the power conductors to external damage.

POWER CONDUCTORS/WEAR

If the power conductors are integral with the tension member and near its surface, some means must be provided to protect against premature wear which could cause malfunction of the hook release mechanism.

POWER CONDUCTORS/FLEXIBILITY

If the power conductors are integral with the tension member, they must be at least as flexible as the load-carrying elements so that they will not break prematurely due to high tensile or bending stresses.

POWER CONDUCTORS/ELASTICITY

If the power conductors are integral with the tension member, they must be at least as elastic (extensible) as the load-carrying elements to assure that they will not break under high loads and maximum tension-member stretch.

POWER CONDUCTORS/TORSIONAL CHARACTERISTICS

If the power conductors are integral with the tension member, they should be designed to accept the torsional loads in the tension member without breakage or fatigue damage. If the power conductors are separate from the tension member, some means must be provided to keep them from becoming twisted around the member.

POWER CONDUCTORS/ANTIROTATION

Antirotation designed into the tension member should impose less stringent design requirements on integral power conductors, and may also eliminate the problem of separate power conductors becoming tangled or wrapping around the outside of the tension member.

POWER CONDUCTORS/STATE OF DEVELOPMENT

Electrical lines integral with the tension member have in the past been the most common method of remote hook control. It may also be possible to use some other method, such as radio frequency transmission, pneumatics, or hydraulics.

POWER CONDUCTORS/KINK RESISTANCE

The power conductors, if integral with the tension member, must be capable of accepting whatever "kink stresses" the tension member will experience. The greater the kink resistance of the tension member, the less the requirement on the power conductors.

POWER CONDUCTORS/ABRASION RESISTANCE

At least as important as the integrity of the tension member is the ability of the power conductors to resist abrasion. This is true even if the conductors are centrally located within the tension member, as internal abrasive wear is a possibility.

POWER CONDUCTORS/FRICTION OR TRACTION DRIVE

The power conductors must be designed to withstand the normal and frictional loads imposed by a friction or traction drive for the tension member.

POWER CONDUCTORS/END CONNECTIONS

See Safety/End Connections.

POWER CONDUCTORS/MINIMUM BEND RADIUS

If the power conductors are integral with the tension member, care must be taken to assure that the conductors as well as the member are capable of sustaining the minimum bend radius without overstress or unacceptable fatigue damage.

POWER CONDUCTORS/REVERSE BENDING

Consideration must be given to the fatigue life of the power conductors under anticipated reverse bending.

STATIC ELECTRICITY/LOAD ACQUISITION

Caution must be exercised when acquiring a load to prevent the static electricity from discharging and injuring personnel or causing a catastrophic event (e.g., igniting gasoline tanks, setting off explosives). The tension member should be grounded prior to contact with loads or personnel.

STATIC ELECTRICITY/EASE OF HANDLING

See Static Electricity/Load Acquisition.

STATIC ELECTRICITY/STATE OF DEVELOPMENT

The static electric charge problem on a helicopter tension member is avoided at present either by contacting the hook with a ground rod or by throwing the "D" ring at the hook. New methods of solving this problem have been suggested and may be developed; these include firing a grounding line from the aircraft, insulating the hook from the tension member, and grounding the gloves of the cargo personnel.

STATIC ELECTRICITY/END CONNECTIONS

It may be possible to design at least part of the lower end connection of the tension member to be nonconductive, reducing the chance of static discharge injuring ground personnel during load acquisition.

LOAD ACQUISITION/EASE OF HANDLING

The ability of a man to handle the tension member, hook, and slings must be considered in the overall design. Ease of hookup to reduce hover time is of primary importance.

LOAD ACQUISITION/THERMAL EFFECTS

Load acquisition should be accomplished smoothly enough that excessive shock loads and consequent thermal damage are not experienced by the tension member. See Shock Loading/Thermal Effects.

LOAD ACQUISITION/FLEXIBILITY

The tension member must be flexible enough so that ground personnel may move the pickup hook directly over the load while the helicopter is hovering. However, it should be stiff enough to prevent the hook from flailing around due either to wind gusts or to helicopter downwash.

LOAD ACQUISITION/ELASTICITY

There are two areas in which the tension-member elastic behavior affects the ease of load acquisition. First, if the tension member is too elastic, vertical oscillations of the hook may develop while the helicopter is hovering over the load, endangering the ground personnel

trying to complete the hookup. Second, a very elastic tension member would mean that during load lift-off, the helicopter would be required to ascend some distance before the load actually lifts off the ground.

LOAD ACQUISITION/TORSIONAL CHARACTERISTICS

A swivel may be required between the tension member and the hook to prevent the load from spinning on lift-off if there is any tendency of the tension member to twist under load.

LOAD RELEASE/THERMAL EFFECTS

Loads should be released in such a manner that excessive shock loads do not occur. Release of cargo while a significant tensile load remains on the tension member can produce spring-back and, possibly, high friction forces and high temperatures. See Shock Loading/Thermal Effects.

LOAD RELEASE/ELASTICITY

The more elastic the tension member, the lower the helicopter must descend or the more the hoist will have to extend to release the load on the hook. This increases the danger of load release under tension, a situation to be avoided because of the stored energy problem.

LOAD RELEASE/STORED ENERGY

Load release from the hook(s) must be accomplished after most of the tension has been let off the tension member, particularly in the case of a very elastic member. See Safety/Stored Energy.

LOAD RELEASE/TORSIONAL CHARACTERISTICS

Because of the problem of stored torsional energy in the tension member, load release should occur under minimum tension conditions; emergency load release may result in whipping of the tension member, endangering personnel and possibly resulting in tension member kinking.

LOAD RELEASE/ANTIROTATION

Antirotation should reduce the stored torsional energy in a loaded tension member so that the member does not spin or twist upon load release.

LOAD RELEASE/KINK RESISTANCE

See Shock Loading/Kink Resistance.

EASE OF HANDLING/MAINTENANCE

The more flexible a tension member is, the more easily a man can handle it during maintenance operations, and the more likely that these operations will be carried out effectively. Ease of field replacement of the tension member is highly desirable.

EASE OF HANDLING/SHAPE

Sharp edges or projections on a tension member could prove dangerous to ground personnel during maintenance or load acquisition. A wide flat section could be hard to handle due to wind loads from gusts and helicopter downwash.

EASE OF HANDLING/FLEXIBILITY

In general, the more flexible the tension member, the more easily it may be handled by ground personnel, both during load acquisition and normal maintenance.

EASE OF HANDLING/TORSIONAL CHARACTERISTICS

Stored torsional energy in the tension member can create a handling problem, both in use and during maintenance. See Safety/Torsional Characteristics.

EASE OF HANDLING/ANTIROTATION

See Safety/Antirotation.

EASE OF HANDLING/WEIGHT

The mass per unit length of the tension member will directly affect the ease with which the member can be handled during load acquisition and normal maintenance.

RELIABILITY/THERMAL EFFECTS

If the design of the tension member is such that damage due to thermal effects is minimized, the system will be inherently more reliable.

RELIABILITY/WEAR

A wear-resistant tension member will be more reliable due to the reduced possibility of wear-induced premature failure.

RELIABILITY/STATE OF DEVELOPMENT

The reliability of any design is directly proportional to its state of development. A newly developed design will have low reliability until proven in use.

RELIABILITY/KINK RESISTANCE

Designed-in kink resistance in a tension member should improve its reliability by guarding against inadvertent failure from kinking.

RELIABILITY/ABRASION RESISTANCE

Proper design attention to abrasion resistance can prevent premature failure due to abrasive wear and improve the reliability of the tension member.

RELIABILITY/END CONNECTIONS

The reliability of the tension-member system is dependent upon the proper design of the end connections to transfer the load from the hook to the member and the hook power from the helicopter to the hook.

MAINTENANCE/SHAPE

See Ease of Handling/Shape.

MAINTENANCE/FLEXIBILITY

See Ease of Handling/Flexibility.

MAINTENANCE/ELASTICITY

If an elastic tension member is stored under tension, great care must be exercised in removing it for maintenance. See Maintenance/Stored Energy.

MAINTENANCE/STORED ENERGY

The tension member may be stored under tension, as with a cable on a drum. If so, extreme care must be exercised to release that tension prior to removing the tension member for maintenance, to preclude the possibility of personnel injury.

MAINTENANCE/WEIGHT

See Ease of Handling/Weight.

MAINTENANCE/END CONNECTIONS

Maintenance of the tension member should be easier if the end connections are designed with quick-release power conductors and other time-saving features to facilitate repair and/or replacement.

SUSCEPTIBILITY TO GUNFIRE/STRENGTH

Generally, the greater the tension-member strength, the less the susceptibility to gunfire damage. One exception is in the case of a nonuniform cross-sectional strength where damage to the stronger area would more severely compromise the strength than damage to the weaker area.

SUSCEPTIBILITY TO GUNFIRE/SHAPE

The shape of the tension member will determine its vulnerability to enemy gunfire; the wider the tension member, the more likely it is to be hit. Also, the design may be such that hits to some areas of the cross section will be more survivable than hits to other areas.

THERMAL EFFECTS/STRENGTH

See Load Capacity/Thermal Effects.

THERMAL EFFECTS/SHAPE

The shape of the tension member may be designed so that rubbing of the member against itself and other parts of the system will produce a minimum of bending and friction, and therefore a minimum of heat build-up.

THERMAL EFFECTS/FLEXIBILITY

If excessive heat buildup creates a phase change in the tension member material, it is possible that the member may become less flexible.

THERMAL EFFECTS/ELASTICITY

If excessive heat buildup creates a phase change in the tension member (such as the embrittlement of synthetic rope), the elasticity of the member may decrease.

THERMAL EFFECTS/STORED ENERGY

The stored energy of a loaded tension member should not be released in such a way as to create excessive heat buildup. See Shock Loading/ Thermal Effects and Load Release/Thermal Effects.

THERMAL EFFECTS/TORSIONAL CHARACTERISTICS

The design of the tension member must allow for the possibility of internal and/or external rubbing under torsional loads. At present, a swivel is provided at the load end of the tension member to accommodate rotation.

THERMAL EFFECTS/FRICTION OR TRACTION DRIVE

If the hoist operation employs a friction or traction drive, consideration must be given to the squeezing or crushing action upon the tension member as well as slippage relative to the traction device. Excessive internal and/or external friction can cause detrimental heat buildup and damage to the tension member material.

THERMAL EFFECTS/MINIMUM BEND RADIUS

The thermal effects due to loading will increase as the minimum bend radius of the tension member decreases. The unit pressure between adjacent component parts of the tension member increases with decreasing bend radius, causing an increased friction load and therefore greater heat energy input.

THERMAL EFFECTS/REVERSE BENDING

Reverse bending of the tension member may increase the relative motion

among the tension member component parts, thus increasing the possibility of damage-causing excessive heat buildup.

THERMAL EFFECTS/FLEET ANGLE

If a tension member is to be wound upon a drum or over a sheave, the fleet angle must be kept to a minimum to reduce scuffing friction which can cause thermal damage. This may require some form of level-wind mechanism.

STRENGTH/WEAR

Any reduction in the tension-member cross-sectional area due to wear will very likely reduce its strength. For this reason, normal wear over the useful life of the tension member must be accounted for in its design. It may be desirable to provide an exterior cover to the load-carrying elements to protect them from degradation due to wear.

STRENGTH/TORSIONAL CHARACTERISTICS

The tension member may be of such a design that induced twisting will unload some of the load-carrying elements. In this case, the load is transferred to a smaller cross section, increasing the stress. Either the tension-member strength must be increased to accommodate this torsional effect, or some form of swivel must be attached to eliminate the torsional load.

STRENGTH/STATE OF DEVELOPMENT

Higher strength materials are continually being developed (e.g., composites). It may be that new, higher strength materials can be useful for the tension member if development work is undertaken to adapt these materials to the tension-member application.

STRENGTH/WEIGHT

It is desirable for the tension member (and the entire hoisting mechanism) to have a high strength-to-weight ratio; for a given strength requirement, the weight should be low to maximize the amount of payload that the helicopter can carry.

STRENGTH/POSITIVE DRIVE

If the tension member is to be hoisted under load by a positive drive

mechanism (such as a sprocket driving a chain), any fittings that the drive engages must be strong enough to support the load.

STRENGTH/END CONNECTIONS

A critical design problem will be the attachment of the end connections (hook) to the tension member in a manner capable of carrying the entire rated load.

STRENGTH/REVERSE BENDING

For the design of the tension member, bending stresses must be considered as well as tensile stresses. It is possible that, due to the configuration, the bending stresses may be the most critical, especially if reverse bending is anticipated.

STRENGTH/COST

For some tension-member materials, greater ultimate tensile stresses may be obtained for increased cost. This represents a design trade-off which must be considered.

SHAPE/WEAR

If the exterior of the tension member has sharp edges or protrusions, it will be more susceptible to wear than if it has smooth outer surfaces. Also, care must be used in the design so that adjacent tension-member parts do not cause detrimental internal wear.

SHAPE/FLEXIBILITY

The cross-sectional shape of the tension member very likely will affect its directional flexibility. For example, a circular cross section will probably be equally flexible in all directions, while a flat-belt or roller-chain configuration will be far stiffer in one direction than another.

SHAPE/NATURAL FREQUENCY

Since the shape of the tension member will determine its lateral stiffness, and the natural frequency is a function of this stiffness, the shape will directly affect the transverse natural frequencies.

SHAPE/ABRASION RESISTANCE

See Shape/Wear. Coatings may be applied to the tension member to improve the abrasion resistance by modifying the surface configuration (shape) to reduce high localized bearing pressures.

SHAPE/FRICTION OR TRACTION DRIVE

If a friction or traction drive is employed to hoist the tension member under load, the member's shape must be such as to withstand the drive loads. For example, a hollow cross section must be strong enough to resist the transverse loads necessary for a frictional driving force.

SHAPE/POSITIVE DRIVE

A positive drive for a tension member utilizes a direct bearing mechanism such as a chain on a sprocket. Because of its high inherent efficiency and small bend radius requirements, positive drive is desirable. However, the tension-member shape necessary for this drive method may require greater complexity and weight.

SHAPE/END CONNECTIONS

The configuration of the tension-member end connections will be determined largely by the member's cross-sectional shape. A wide flat belt may be difficult to terminate, since it would be necessary to transfer the load uniformly from the entire width of the belt to a central point (hook center).

SHAPE/MINIMUM BEND RADIUS

See Shape/Flexibility. Generally, the more flexible a tension member (as determined by its shape), the smaller will be the minimum allowable bend radius.

SHAPE/REVERSE BENDING

It may be undesirable to reverse bend a tension member because of its shape and the resulting high bending stresses (e.g., a "V" belt construction).

SHAPE/FLEET ANGLE

The shape of the tension member may determine its transverse stiffness;

high transverse stiffness may reduce the maximum allowable fleet angle because of stress considerations.

WEAR/ABRASION RESISTANCE

The tension member should possess good abrasion resistance so that external wear is reduced to a minimum.

WEAR/FRICTION OR TRACTION DRIVE

Minor slippages occur in traction-type hoist drives due to the differences in tension-member load from full tension at the entry to back tension at the exit of the traction drive mechanism. This slippage causes wear on the outer surface of the tension member. Internal wear may be caused in the same manner due to relative movement between tension-member elements.

WEAR/POSITIVE DRIVE

The wear associated with a positive drive system is concentrated at the joints of the tension member, if any, and at the points of contact with the driving sprockets or tracks. However, with this type of drive, tension-member lubrication may be used without degrading the tractive effort.

WEAR/MINIMUM BEND RADIUS

For some tension-member designs, the smaller the bend radius experienced, the greater the relative movement between adjacent elements, and thus the greater the internal wear.

WEAR/FLEET ANGLE

If a tension-member fleet angle is too great, it is likely that the tension member will scuff both on itself and on the system machinery.

FLEXIBILITY/NATURAL FREQUENCY

The lateral natural frequency of the tension member is a function of its flexibility.

FLEXIBILITY/KINK RESISTANCE

It is likely that the more flexible the design of the tension member, the more resistant it will be to damage due to kinking.

FLEXIBILITY/MINIMUM BEND RADIUS

Generally, the more flexible a tension member, the lower will be its bending stresses for a given bend radius and the smaller will be the minimum allowable bend radius.

ELASTICITY/NATURAL FREQUENCY

The longitudinal natural frequency of the tension member is inversely proportional to its elasticity, while the lateral natural frequency is inversely proportional to the elasticity and directly proportional to the applied tension.

ELASTICITY/STORED ENERGY

The more elastic the tension member, the greater its deflection under load; since the stored energy is the product of the load and the deflection, the greater will be the stored energy. See Safety/Stored Energy.

ELASTICITY/FRICTION OR TRACTION DRIVE

With a friction or traction drive, the system must be designed to accommodate the elastic elongation of the tension member under load and the reduction in length when the tension member comes off the drive at low tension into storage. Also to be considered are the slippage and possible abrasive wear due to the tension change over the tractive drive element.

ELASTICITY/POSITIVE DRIVE

Because of the nature of a positive drive system, it is quite likely that very little elasticity can be tolerated in its tension member. If, for instance, roller chain were used as the tension member, too great an elongation under load would result in the chain not meshing properly with the driving sprocket.

NATURAL FREQUENCY/DAMPING

If the system design includes a generous amount of damping, it may be

possible to experience forced vibration at or near the system natural frequency without undue safety hazard. It is likely that, in transitioning from hover to forward flight, for example, the fundamental natural frequency of the tension member will be excited, necessitating designed-in system damping to minimize harmonic oscillation.

TORSIONAL CHARACTERISTICS/ANTIROTATION

Antirotation is that generally desirable torsional design characteristic of a tension member which minimizes twist under load.

TORSIONAL CHARACTERISTICS/KINK RESISTANCE

If the tension member is not torsionally stable, it will probably not be kink resistant under twisting loads, sudden load release, or change from high tension to low back-tension in the hoist system.

TORSIONAL CHARACTERISTICS/FRICTION OR TRACTION DRIVE

A friction or traction drive must take into account any twisting of a tension member when passing from high to low tension. See also Storage/Torsional Characteristics.

TORSIONAL CHARACTERISTICS/END CONNECTIONS

See Load Acquisition/Torsional Characteristics.

ANTIROTATION/KINK RESISTANCE

A tension member designed to be antirotative is less likely to kink from the release of stored torsional energy, as when a load is released or when the member comes off a friction drive into storage.

ANTIROTATION/FRICTION OR TRACTION DRIVE

See Torsional Characteristics/Friction or Traction Drive.

ANTIROTATION/END CONNECTIONS

Antirotation may eliminate the requirement for a swivel at the hook for multipoint suspension configurations.

STATE OF DEVELOPMENT/COST

Generally, the greater the state of development, the lower the cost of implementing a tension-member concept.

WEIGHT/FRICTION OR TRACTION DRIVE

The weight of a tension member may be less for a friction-drive type than for a positive-drive type. However, the hoist drive system for the positive drive may weigh less than for a friction drive, offering an overall system weight saving.

WEIGHT-POSITIVE DRIVE

See Weight/Friction or Traction Drive.

KINK RESISTANCE/MINIMUM BEND RADIUS

The minimum bend radius experienced by a tension member must not be so small as to produce permanent tension-member kinking under the maximum loading conditions.

ABRASION RESISTANCE/FRICTION OR TRACTION DRIVE

The overall abrasion resistance of a tension member used for a friction drive may have to be greater than that for a positive-drive system. The elastic nature of the tension member may result in differential sliding movement in the traction-drive system with resultant abrasive surface wear of the tension member.

ABRASION RESISTANCE/POSITIVE DRIVE

Abrasion may be a problem at the positive-drive contact points on the tension member. See Abrasion Resistance/Friction or Traction Drive.

ABRASION RESISTANCE/FLEET ANGLE

Even a small fleet angle may cause scuffing contact between tension-member elements as the member retracts into storage; for this reason, abrasion resistance is important.

MINIMUM BEND RADIUS/REVERSE BENDING

Because fatigue damage is related not only to maximum stress but also

to mean stress, reverse bending of the tension member is likely to require a larger minimum bend radius to avoid unacceptable fatigue damage.

MINIMUM BEND RADIUS/FLEET ANGLE

Design attention must be paid to the bend radius experienced by the tension member due to fleet angle. In some cases this radius is the smallest bend radius in the system.

APPENDIX II

DISCUSSION AND EVALUATION OF TENSION-MEMBER CONCEPTS FOR EACH PARAMETER

Each tension-member concept has been evaluated with regard to each parameter in light of the preceding questions. Values of one through ten have been assigned, with higher numbers indicating higher rating.

EASE OF GUILLOTINING

Guillotining the tension member may be accomplished with a mechanically released spring-loaded cutting blade, an explosive-powered cutting blade, or a shaped charge such that the explosive energy itself cuts through the tension member. Preliminary consideration of these guillotining techniques indicates that for each of the several tension-member concepts, a feasible guillotine system can be designed with suitable reliability using one or more of the methods just described.

A cutting blade and anvil arranged to sever the tension member by a chisel action probably would be suitable for the wire rope, synthetic rope and wire-rope-belt configurations. A cutting blade and anvil arranged to sever the tension member by a scissor action might be satisfactory for the synthetic-tape and steel-tape concepts. For either case, the metallic tension members would require more energy to accomplish guillotining than would the synthetic ones. The roller-chain and jointed-link concepts would require a more sophisticated guillotine system since energy would be required to cut through the rollers (as well as links) or the joint areas, respectively. The evaluation in Table XI covers all load cases.

TABLE XI. EASE OF GUILLOTINING EVALUATION

Concept	Metallic Material	High Required Energy	Evaluation
D. Synthetic Rope			10
E. Synthetic Tape			10
C. Steel Tape	x		9
A. Wire Rope	x		8
B. Wire-Rope Belt	x		6
G. Jointed Links	x	x	4
F. Roller Chain	x	x	3

STORED ENERGY - ELASTICITY

A very real danger exists in the operation of the hoist system if the cargo is released prior to reducing the tension in the tension member to a safe level. This might happen either in an emergency or inadvertent release of suspended cargo or by hook release during cargo delivery prior to fully removing the load. A third situation sometimes encountered is sling or hook failure, resulting in immediate loss of tension. The danger lies in the stored strain energy of the tension member causing the hook to recoil upward into the helicopter rotors or fuselage. Each tension-member concept is analyzed below for the magnitude of this danger utilizing the following approach:

Assuming that the tension member acts as a linear spring under load,

$$\text{Stored energy} = 1/2\ k\delta^2 \tag{4}$$

where

k = spring constant (lb/in.)

δ = elongation (in.)

For an elastic member, the elongation under load is

$$\delta = \frac{P\ell}{AE} \tag{5}$$

where

P = applied load (lb)

ℓ = length (in.)

A = cross-sectional area (in.^{2})

E = elastic modulus (lb/in.^{2})

For a linear system,

$$k = \frac{P}{\delta} = \frac{AE}{\ell} \tag{6}$$

Then the stored energy $= \frac{1}{2} k\delta^2 = \frac{1}{2} \frac{AE}{\ell} \left(\frac{P\ell}{AE}\right)^2 = \frac{P^2\ell}{2AE}$

Assuming a conservative system (no energy loss) and a weightless tension member, the stored energy is equal to the energy expended to launch the hook:

$$\frac{P^2\ell}{2AE} = W_H\ y$$

where

W_H = hook weight (lb)

y = rebound height (in.)

Rearranging, $\quad y/\ell = \dfrac{P^2}{2AEW_H}$

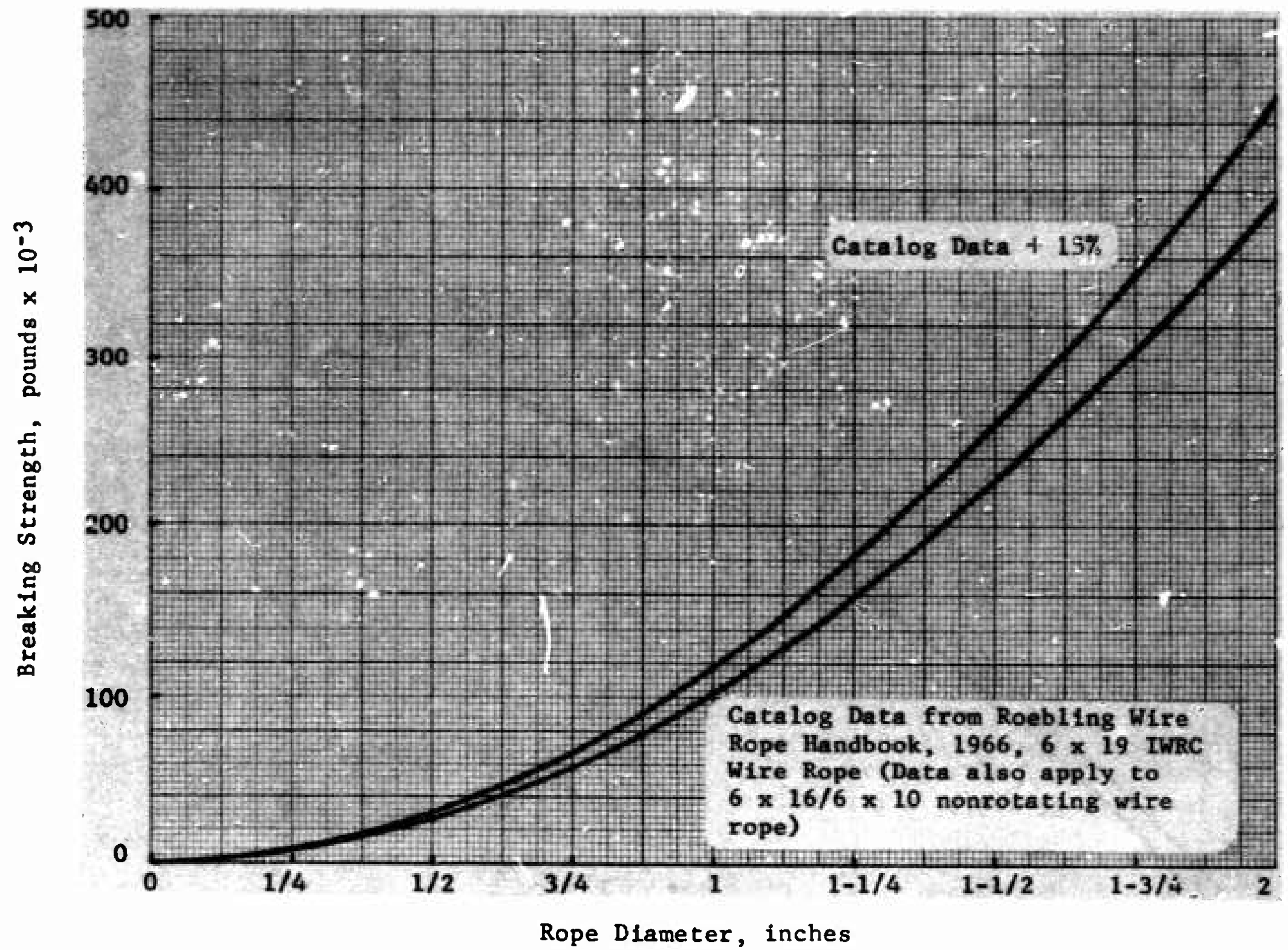

Figure 17. Wire-Rope Breaking Strength Versus Rope Diameter.

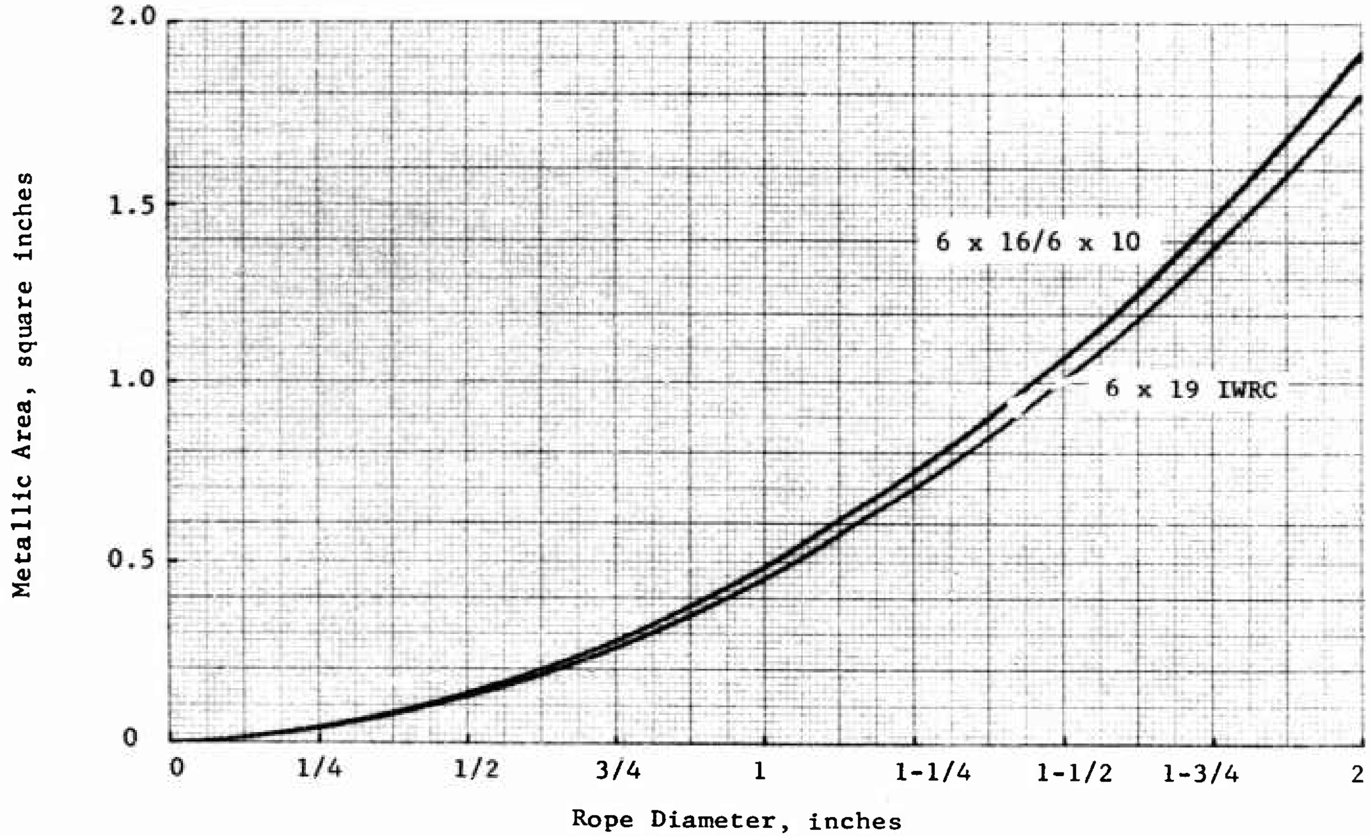

Figure 18. Wire-Rope Metallic Area Versus Rope Diameter.

B. Wire-Rope Belt

The same analysis applied to wire-rope belt comprised of four 6 x 19 IWRC ropes gives the values in Table XIII (assuming the rope elastic modulus = 14.5×10^6 psi).

TABLE XIII. STORED ENERGY - WIRE-ROPE BELT

Load Case	Rope Diameter (in.)	Ultimate Tensile Strength ($lb \times 10^{-3}$)	Metallic Area ($in.^2$)	DHR ($lb \times 10^{-3}$)	DHR (Percent of Design Capacity)
30T-1	11/16	232	0.88	84.6	141
40T-1	13/16	320	1.20	109.0	136
50T-1	15/16	416	1.60	136.5	137
30T-2	9/16	156	0.60	57.6	139
40T-2	11/16	232	0.88	77.5	140
50T-2	3/4	271	1.04	92.0	133

For both concepts A and B, then, release of the hook with partial load when delivering cargo presents no danger to the aircraft fuselage or rotor. However, hook release or sling breakage under high "G" loads from gusts or maneuvers can result in the hook being launched far enough to endanger the safety of the aircraft and crew.

C. Steel Tape

Conservatively, the same analysis may be applied to the steel-tape concept; the results are shown in Table XIV.

TABLE XIV. STORED ENERGY - STEEL TAPE

Load Case	Ultimate Tensile Strength ($lb \times 10^{-3}$)	Tape Dimensions (in.)	Metallic Area ($in.^2$)	DHR* ($lb \times 10^{-3}$)	DHR (Percent of Design Capacity)
30T-1	225	1/8 x 6.00	0.75	113.7	190
40T-1	300	1/8 x 8.00	1.00	144.8	181
50T-1	375	1/8 x 10.00	1.25	175.7	176
30T-2	155	1/8 x 4.14	0.52	78.0	188
40T-2	207	1/8 x 5.52	0.69	100.0	181
50T-2	259	1/8 x 6.91	0.86	121.8	176

*For this calculation the elastic modulus of the steel tape is assumed to be 30.7×10^6 psi.

D. Synthetic Rope

Because of the nonlinear behavior of the double-braid rope construction, each load case must be analyzed using the typical stress-strain curve shown in Figure 19. The stored energy was computed by graphical integration from the percentage-load-versus-elongation curve for a double-braid construction with a polyester outer cover and a polypropylene inner core; the breaking strengths were increased by 10 percent to reflect the latest developments in synthetic (polyester) fibers Polyester fibers (Dacron, Fortrel, etc.) show the greatest promise for this application due to a favorable combination of high strength, low elongation, and high melting point. The results of this analysis are shown in Table XV.

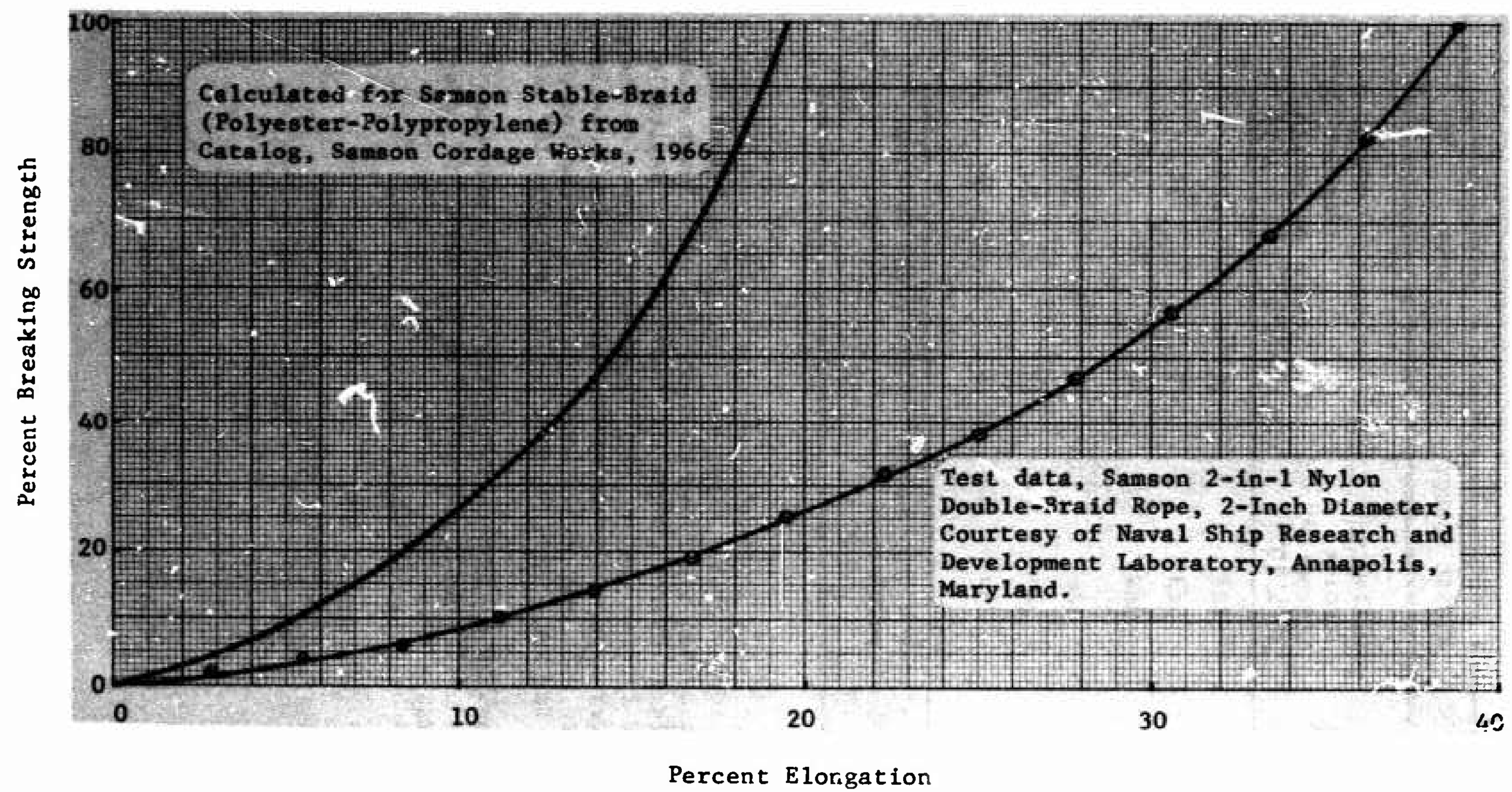

Figure 19. Synthetic-Rope Elastic Behavior.

TABLE XV. STORED ENERGY - SYNTHETIC ROPE				
Load Case	Rope Diameter (in.)	Ultimate Tensile Strength* (lb x 10^{-3})	DHR (lb x 10^{-3})	DHR (Percent of Design Capacity)
30T-1	2-3/4	225	15	25
40T-1	3-1/4	303	19	24
50T-1	3-3/4	384	24	24
30T-2	2-3/8	164	11	26
40T-2	2-5/8	207	13	24
50T-2	3	264	16	24

*Ultimate tensile strength from Samson Cordage Works Catalog, 1966, increased by 10 percent.

E. Synthetic Tape

Breaking strength data for synthetic tapes are presented in Figure 20. Typical load-elongation curves are shown in Figure 21. The lower elongation of the polyester (e.g.,Dacron) makes this material most desirable for the helicopter-load tension member. For purposes of computing energy storage for the polyester tape, a linear approximation of the load-elongation curve may be used with acceptable accuracy. This assumption provides an approximation for the elastic modulus equal to 0.63 x 10^6 psi.

Computations for tension-member load corresponding to Dangerous Hook Release can now be made utilizing Equation (7) and Figures 2, 20, and 21 to give the values in Table XVI.

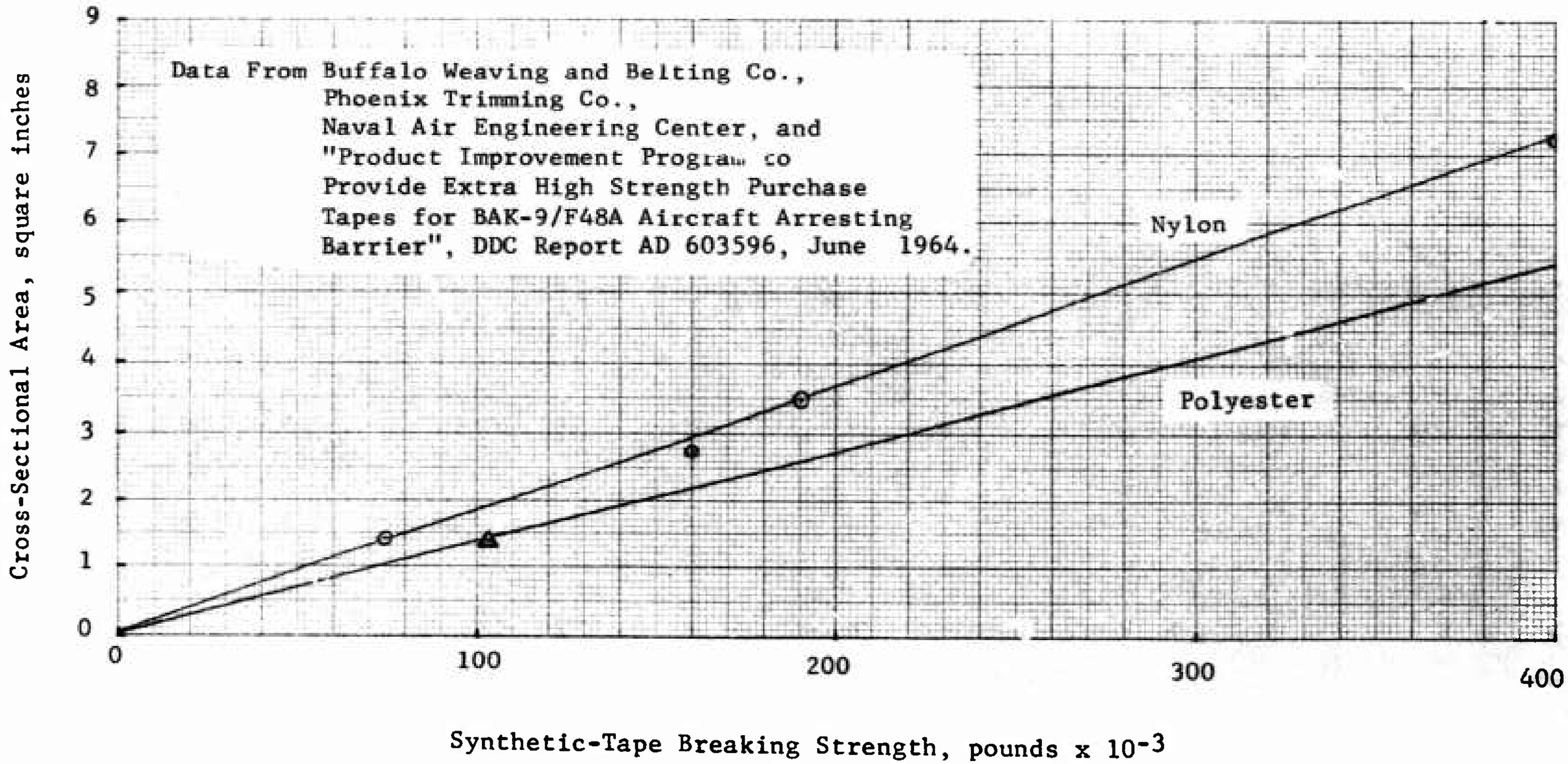

Figure 20. Synthetic-Tape Cross-Sectional Area Versus Breaking Strength.

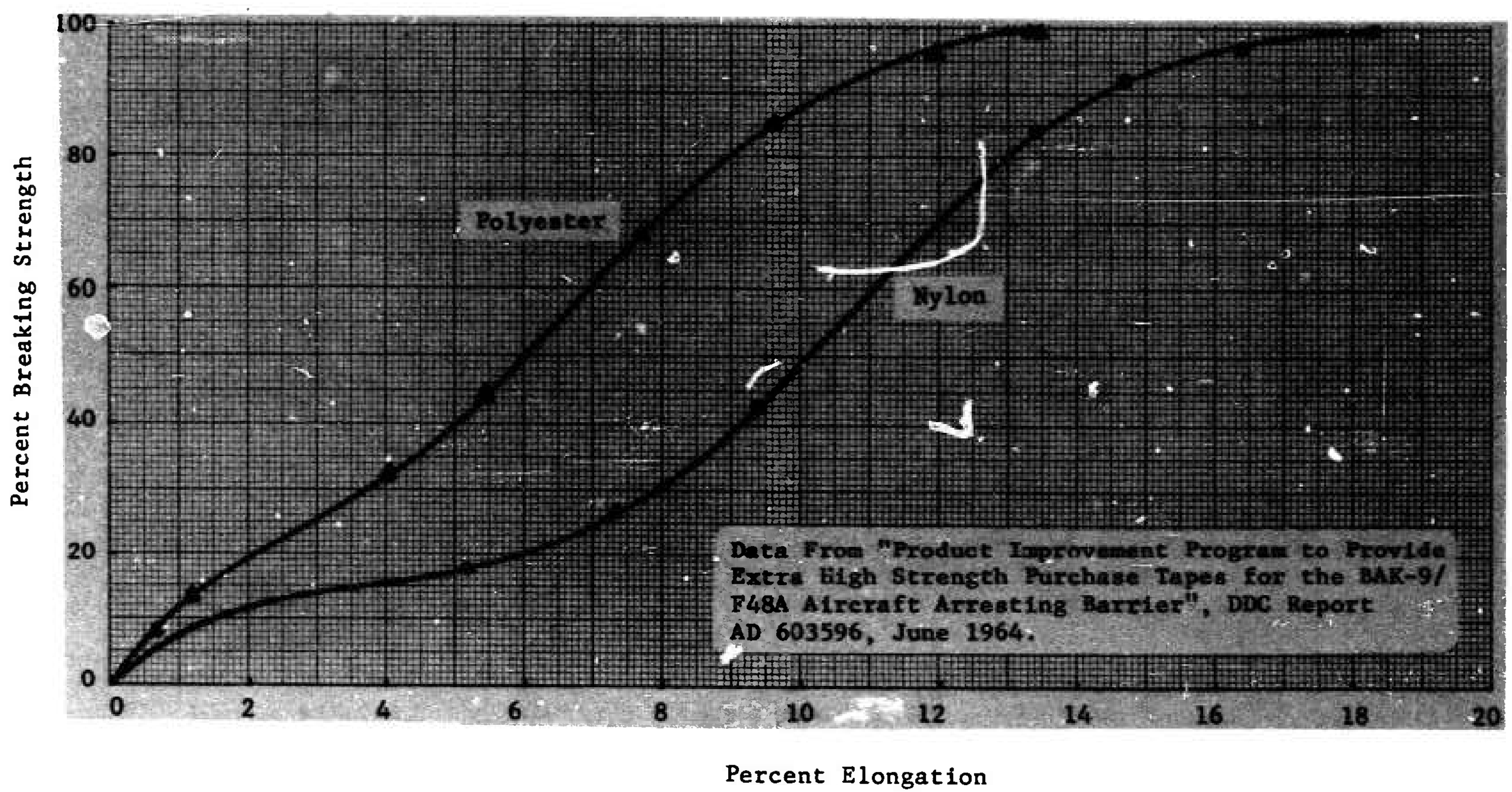

Figure 21. Typical Load-Elongation Curves for Synthetic Tapes.

TABLE XVI. STORED ENERGY - SYNTHETIC TAPE			
Load Case	Tape Dimensions (in.)	DHR (lb x 10^{-3})	DHR (Percent of Design Capacity)
30T-1	7.65 x 0.40	33	55
40T-1	10.20 x 0.40	42	52
50T-1	12.75 x 0.40	51	51
30T-2	5.25 x 0.40	22	53
40T-2	7.05 x 0.40	29	52
50T-2	8.80 x 0.40	35	51

F. Roller Chain

The following load-elongation data were obtained from a roller-chain manufacturer:

	ASA 160 Chain	ASA 200 Chain
Tensile load, T, pounds	17,500	19,000
Strain, ε, inches per foot	0.050	0.030
Metallic area, A, square inches	0.61	1.00

The elastic moduli of these two chain types may be computed as

$$E = \frac{\sigma}{\varepsilon} = \frac{T}{\varepsilon A} \tag{8}$$

Elastic moduli values of 6.9 x 10^6 psi and 7.6 x 10^6 psi are obtained for the ASA 160 and ASA 200 chains, respectively.

For n-strand chains (i.e., ASA 160-n), the metallic area will be n times the above-indicated values, and an applied load of n times the indicated value will produce the same elongation as listed above. Table XVII gives the results of the analysis for the six load cases.

TABLE XVII. STORED ENERGY - ROLLER CHAIN				
Load Case	Chain ASA Number	Ultimate Tensile Strength* (lb x 10^{-3})	DHR (lb x 10^{-3})	DHR (Percent of Design Capacity)
30T-1	160-4	232	97	162
40T-1	160-6	348	131	164
50T-1	200-4	380	156	156
30T-2	160-3	174	69	167
40T-2	160-4	232	89	161
50T-2	200-3	285	113	164

*Diamond Chain Company, Catalog No. 766.

G. Jointed Links

Without a detailed design for each load capacity requirement, an exact calculation of stored energy effect is not possible for the jointed-link tension-member concept. However, a look at the construction reveals that the modulus will certainly be lower than that of the material used in each link (due to local deformations at the joints) and will probably be higher than that of roller chain due to the smaller number of link connections.

The estimated values given in Table XVIII assume that the effective elastic modulus of jointed links is 20 x 10^6 psi.

TABLE XVIII. STORED ENERGY - JOINTED LINKS			
Load Case	Ultimate Tensile Strength (lb x 10^{-3})	DHR (lb x 10^{-3})	DHR (Percent of Design Capacity)
30T-1	225	130	217
40T-1	300	165	206
50T-1	375	200	200
30T-2	155	89	215
40T-2	207	114	206
50T-2	259	139	202

In Table XIX, the tension-member concepts are listed in order of decreasing Dangerous Hook Release load as a percentage of rated load capacity. The concepts are evaluated by comparison using the graph shown in Figure 22. Below 100 percent DHR load, there is danger both from release of a capacity load under tension and from inadvertent dropping of the load due to sling or hook failure. Above 100 percent DHR load, the danger lies only in sling failure or hook release under high "G" loading.

TABLE XIX. STORED ENERGY EVALUATION

Concept		Load Case					
		30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
G. Jointed Links[a]	DHR[b]	217	206	200	215	206	202
	EV[c]	10	10	10	10	10	10
F. Roller Chain[a]	DHR	162	164	156	167	161	164
	EV	10	10	10	10	10	10
C. Steel Tape	DHR	190	181	176	188	181	176
	EV	9	8	8	8	8	8
B. Wire-Rope Belt	DHR	141	136	137	139	140	133
	EV	7	7	7	7	7	7
A. Wire Rope	DHR	140	136	132	144	139	132
	EV	7	7	7	7	7	7
E. Synthetic Tape	DHR	55	52	51	53	52	51
	EV	3	3	3	3	3	3
D. Synthetic Rope	DHR	25	24	24	26	24	24
	EV	1	1	1	1	1	1

(a) The very large total weight of the jointed-link and roller chain tension members will act to prevent dangerous recoil of hook. Therefore, these two tension-member concepts are given the maximum evaluation of 10.

(b) Dangerous Hook Release load, percent of design capacity.

(c) Evaluation.

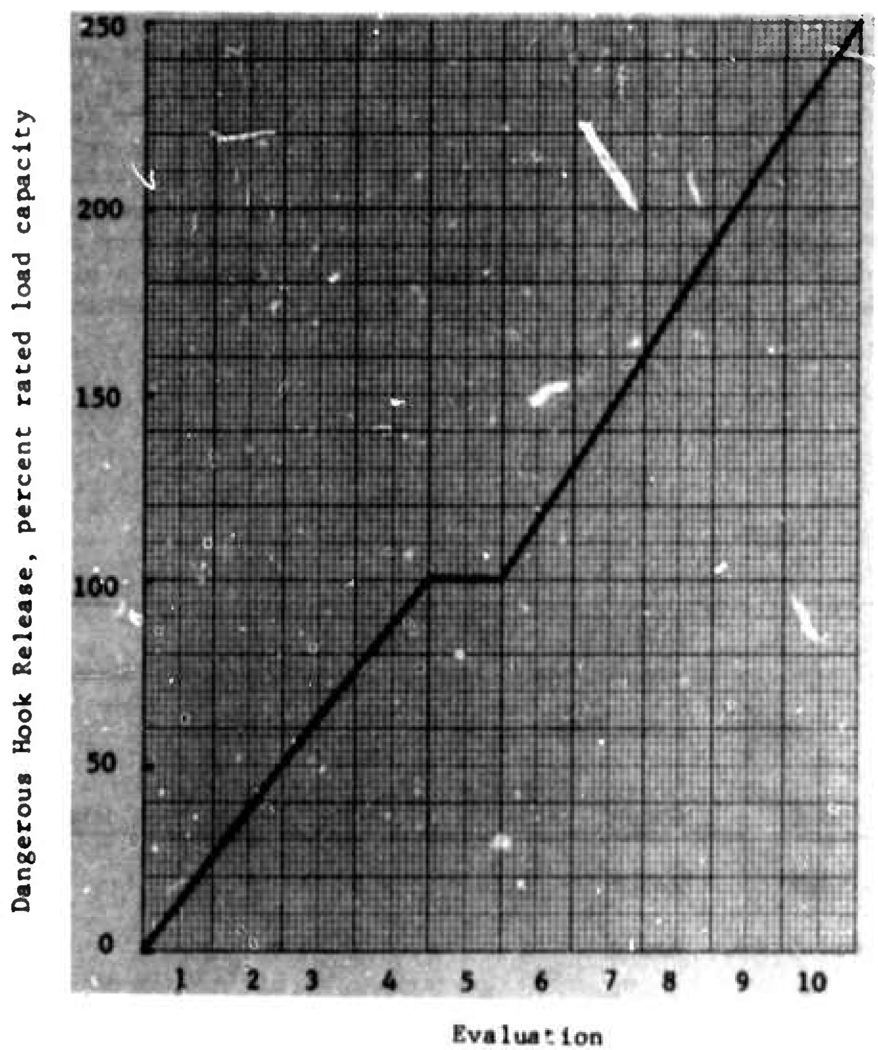

Figure 22. Evaluation of Stored Energy for Tension-Member Concepts.

AERODYNAMIC CONSIDERATIONS

The flight stability of the various tension-member concepts is a measure of detrimental aerodynamic effects during operation. In this respect, both the shape and the weight will affect the magnitude and frequency of aerodynamic vibrations as well as the amount of drag. Shapes may be compared by analyzing the width-to-thickness ratio of the tension-member cross sections. This parameter influences the "flapping" or vortex-shedding behavior; higher values of the ratio indicate more serious vibration. Also, the drag of the tension member is directly proportional to the projected area (or width) perpendicular to the airstream. The weight of the tension member affects the frequency of vibration; higher weight is usually associated with lower frequency and higher amplitude. The evaluation in Table XX considers both the aerodynamic effect of shape and the expected effect of weight differences on vibration frequencies.

TABLE XX. AERODYNAMIC EVALUATION

Concept	Drag: Shape	Drag: Relative Width	Flutter: Width/Thickness Ratio	Flutter: Relative Weight	Evaluation
A. Wire Rope	Round	1	1	2	9
G. Jointed Links	Round	1	1	3	9
D. Synthetic Rope	Round	2	1	1	8
B. Wire-Rope Belt	Flat	2	4	2	7
F. Roller Chain	Flat, but open	6	4-8	12	7
E. Synthetic Tape	Flat	5	13-32	1	5
C. Steel Tape	Flat	4	30-80	1	4

RESISTANCE TO SHOCK LOADING

The resistance of a tension member to excessive transient tensions during shock or impact loading may be viewed as a measure of elasticity or spring rate. That is, the more elastic a tension member, the less likely it will break under a given impact loading. A study of the parameters affecting impact tolerance* shows that for linear material under longitudinal impact conditions, the tolerance is directly proportional to the ultimate tensile stress and inversely proportional to the square root of the modulus and the mass density:

$$\text{Impact tolerance} \propto \frac{\sigma_{ult}}{E\rho} \qquad (9)$$

where

σ_{ult} = (UTS)/A (lb/in.^{2})

ρ = (wt)/Aℓg (lb/in.^{3})

E = elastic modulus of tension member (lb/in.^{2})

UTS = ultimate tensile strength of tension member (lb)

A = cross-sectional area of tension member (in.^{2})

ℓ = total length of tension member (in.)

wt = total weight of tension member (lb)

g = acceleration of gravity (in./sec^2)

Then,

$$\text{Impact Tolerance} \propto \frac{(UTS)/A}{\sqrt{E(wt)/A\ell g}} \qquad (10)$$

For all tension-member concepts, ℓ and g are constants, and therefore

$$\text{Impact tolerance} \propto UTS/\sqrt{EA\ (wt)} \qquad (11)$$

Table XXI gives the results of an impact tolerance analysis for the several tension-member concepts. In cases of nonlinear stress-strain behavior where the elastic modulus decreases with strain, such as synthetic tape and rope, the impact tolerance will be higher than that computed using a linear approximation of modulus based on the strain at failure; results for those concepts will therefore be conservative.

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*ASD Technical Note 61-66 AN INVESTIGATION OF THE MATERIALS AND CONSTRUCTIONS OF TENSION MEMBERS FOR USE IN AIRCRAFT ARRESTMENT EQUIPMENT, June 1961. Armed Services Technical Information Agency.

TABLE XXI. IMPACT TOLERANCE

Concept	Elastic Modulus ($lb/in.^2 \times 10^{-6}$)	Breaking Strength ($lb \times 10^{-3}$)	Metallic Area ($in.^2$)	Weight (lb/100 ft)	Comparative Impact Tolerance
		Load Case: 30T-1			
A. Wire Rope	13.5	225	0.93	377	3.27
B. Wire-Rope Belt	14.5	232	0.88	353	3.45
C. Steel Tape	30.7	225	0.75	255	2.93
D. Synthetic Rope	0.19	225	5.94	206	14.75
E. Synthetic Tape	0.63	225	3.06	144	13.50
F. Roller Chain	6.9	232	2.44	2530	1.13
G. Jointed Links	20.0	225	1.50	600	1.68
		Load Case: 40T-1			
A. Wire Rope	13.5	304	1.29	525	3.18
B. Wire-Rope Belt	14.5	320	1.20	481	3.49
C. Steel Tape	30.7	300	1.00	340	2.94
D. Synthetic Rope	0.19	303	8.30	280	14.40
E. Synthetic Tape	0.63	300	4.08	192	13.50
F. Roller Chain	6.9	348	3.65	3780	1.13
G. Jointed Links	20.0	300	2.00	800	1.68

TABLE XXI - Continued

Concept	Elastic Modulus ($lb/in.^2 \times 10^{-6}$)	Breaking Strength ($lb \times 10^{-3}$)	Metallic Area ($in.^2$)	Weight (lb/100 ft)	Comparative Impact Tolerance
		Load Case: 50T-1			
A. Wire Rope	13.5	376	1.61	654	3.15
B. Wire-Rope Belt	14.5	416	1.60	641	3.40
C. Steel Tape	30.7	375	1.25	425	2.93
D. Synthetic Rope	0.19	384	11.05	357	14.00
E. Synthetic Tape	0.63	375	5.10	240	13.50
F. Roller Chain	7.6	380	3.99	4290	1.05
G. Jointed Links	20.0	375	2.50	1000	1.68
		Load Case: 30T-2			
A. Wire Rope	13.5	166	0.69	281	3.24
B. Wire-Rope Belt	14.5	156	0.60	240	3.41
C. Steel Tape	30.7	155	0.52	177	2.91
D. Synthetic Rope	0.19	164	4.43	150	14.60
E. Synthetic Tape	0.63	155	2.10	99	13.50
F. Roller Chain	6.9	174	1.83	1900	1.13
G. Jointed Links	20.0	155	1.03	415	1.68

TABLE XXI - Continued

	Concept	Elastic Modulus ($lb/in.^2 \times 10^{-6}$)	Breaking Strength ($lb \times 10^{-3}$)	Metallic Area ($in.^2$)	Weight (lb/100 ft)	Comparative Impact Tolerance
			Load Case: 40T-2			
A.	Wire Rope	13.5	225	0.93	377	3.27
B.	Wire-Rope Belt	14.5	232	0.88	353	3.46
C.	Steel Tape	30.7	207	0.69	234	2.93
D.	Synthetic Rope	0.19	207	5.41	188	14.90
E.	Synthetic Tape	0.63	207	2.81	132	13.50
F.	Roller Chain	6.9	232	2.44	2530	1.13
G.	Jointed Links	20.0	207	1.38	550	1.68
			Load Case: 50T-2			
A.	Wire Rope	13.5	262	1.10	449	3.21
B.	Wire-Rope Belt	14.5	271	1.04	416	3.42
C.	Steel Tape	30.7	259	0.86	292	2.95
D.	Synthetic Rope	0.19	264	7.06	240	14.70
E.	Synthetic Tape	0.63	259	3.52	165	13.50
F.	Roller Chain	7.6	285	2.99	3230	1.05
G.	Jointed Links	20.0	259	1.73	690	1.68

Using a linear evaluation of impact tolerance as shown in Figure 23, the values shown in Table XXII are generated.

TABLE XXII. EVALUATION OF RESISTANCE TO SHOCK LOADING

Concept		Load Case 30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
D. Synthetic Rope	IT*	14.75	14.40	14.00	14.60	14.90	14.70
	EV**	10	10	10	10	10	10
E. Synthetic Tape	IT	13.50	13.50	13.50	13.50	13.50	13.50
	EV	10	10	10	10	10	10
B. Wire-Rope Belt	IT	3.45	3.49	3.40	3.41	3.46	3.42
	EV	3	3	3	3	3	3
A. Wire Rope	IT	3.27	3.18	3.15	3.24	3.27	3.21
	EV	3	3	3	3	3	3
C. Steel Tape	IT	2.93	2.94	2.93	2.91	2.93	2.95
	EV	2	2	2	2	2	2
G. Jointed Links	IT	1.68	1.68	1.68	1.68	1.68	1.68
	EV	2	2	2	2	2	2
F. Roller Chain	IT	1.13	1.13	1.05	1.13	1.13	1.05
	EV	1	1	1	1	1	1

* Impact Tolerance.

** Evaluation.

RESISTANCE TO THERMAL DAMAGE

Thermal damage to the tension member may occur in several ways. During normal extend-and-retract operations under load or during periods of shock loading, heat may be generated by sliding friction as the tension member rubs against components of the hoist system or against adjacent layers or wraps of the tension member on a hoist drum. Another source of heat is prolonged vibration due to aerodynamic instability of the tension member. This latter condition may provide surface damage to the tension member in contact areas with hoist components, or internal damage due to working of the load-carrying elements.

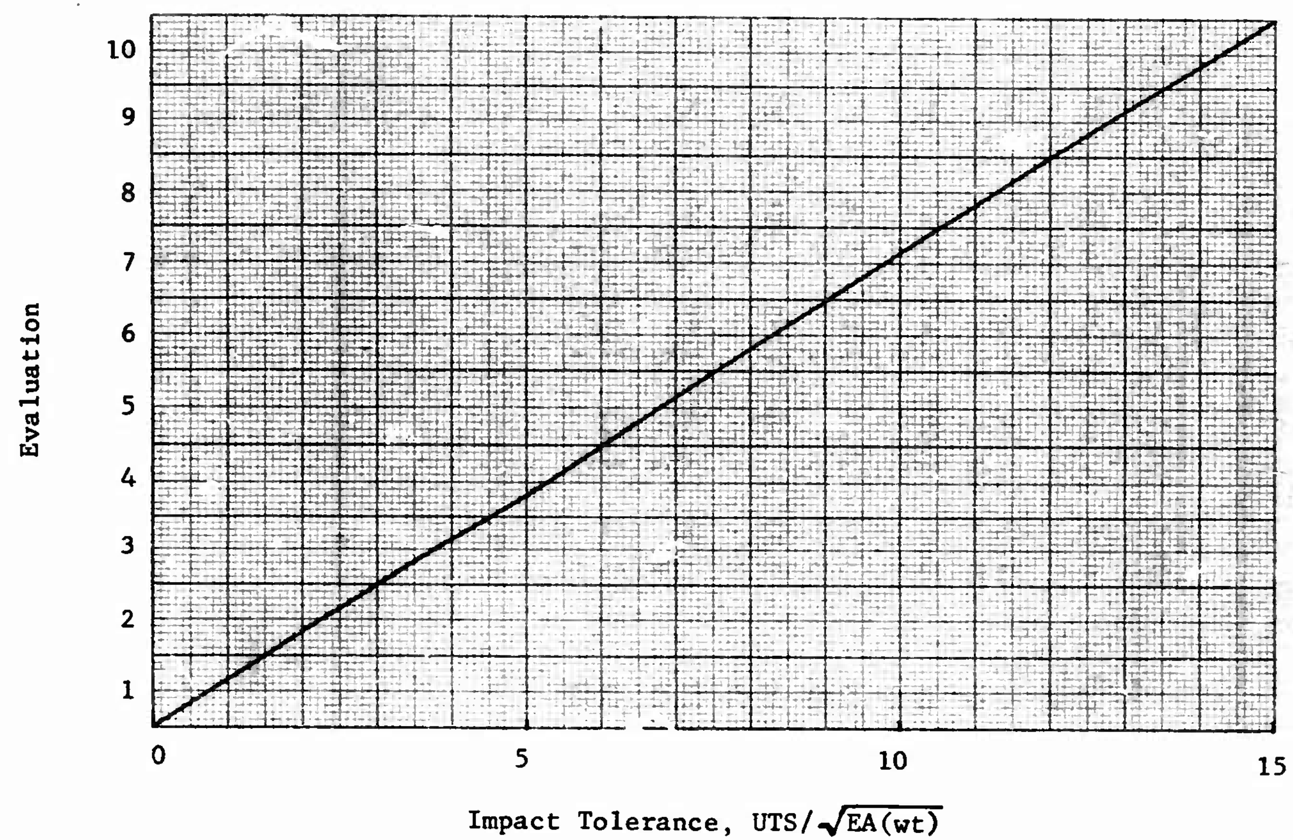

Figure 23. Evaluation of Tension-Member Concepts by Impact Tolerance.

In regard to the synthetic materials, there have been some reports of embrittlement of nylon cargo slings due to excessive heat buildup at contact points with the cargo. On the other hand, the Navy has experienced no problems of this nature in the operation of their synthetic-tape aircraft-arresting equipment under extremely severe impact-loading conditions. (The arresting tapes are similar in size and design to the proposed synthetic-tape tension member.) It is probable that in this latter case, the large contact areas and resulting low unit pressures result in minimum heat generation during impact. Thermal effects, then, on synthetic rope might be expected to be more pronounced because of smaller contact areas and higher unit pressures.

Wire-rope constructions comprised of carbon steel wires can generate enough heat and pressure at contact points with sheaves and drums during impact conditions to cause a martensitic phase change in the wire material. The result is a very brittle and crack-sensitive surface layer which accelerates fatigue failure of the wires.

The evaluation shown in Table XXIII illustrates the measure of the tension member's resistance to permanent damage from heat buildup under operating loads.

TABLE XXIII. EVALUATION OF RESISTANCE TO THERMAL DAMAGE

Concept	Resistance to Thermal Damage	Evaluation
C. Steel Tape	High	10
F. Roller Chain	High	10
G. Jointed Links	High	10
B. Wire-Rope Belt	High (has protective encapsulation)	9
A. Wire Rope	Moderate (can form martensite under severe operating conditions)	8
E. Synthetic Tape	Moderate (low melting-point material)	6
D. Synthetic Rope	Low (low melting-point material and high unit pressures)	4

RESISTANCE TO ENVIRONMENTAL DAMAGE

Resistance to environmental effects is essentially a measure of the possible degradation of tension-member strength due to external environmental conditions. These conditions include strong sunlight, high humidity, blowing sand and dust, acidic or alkaline contamination, and extremes of temperature. The synthetics are known to experience a reduction in strength after prolonged exposure to sunlight, although coatings and additives are available which greatly reduce this effect. Synthetic fibers can be susceptible to weakening in some strong acids or alkalis, and nylon is known to be degraded by water absorption; but, again, suitable coatings probably can reduce these problems. Blowing sand and dust will likely not affect suitably coated synthetic fibers.

High humidity may cause surface corrosion on metallic tension members, depending on the material used. Blowing sand and dust can result in fatigue-crack-producing nicks and scratches. Wire rope is susceptible to internal damage from intrusion of sand and grit. The exception is wire-rope belt; assuming that the outer covering remains intact, wire-rope belt is unaffected by any of the above-mentioned environmental conditions.

External temperatures above 120° F are not expected, and temperatures within the aircraft may be only slightly higher. The melting point of the proposed synthetic fibers (approximately 500° F) and the transition temperatures of the steels anticipated for use in several tension-member concepts (on the order of 1000° F) suggest that these expected ambient temperatures should have little or no effect on these materials. There is a chance, however, that extremes of arctic cold might cause embrittlement of the synthetic materials.

Table XXIV shows the evaluation of each tension member's susceptibility to environmental degradation.

TABLE XXIV. EVALUATION OF RESISTANCE TO ENVIRONMENTAL DAMAGE

	Affected by*					
Concept	Sunlight	Moisture	Sand and Dust	Acids and Alkalis	Extremes of Temperature	Evaluation
B. Wire-Rope Belt			x-	x-		9
E. Synthetic Tape (coated)	x-		x-	x-	x	7
D. Synthetic Rope (coated)	x-		x	x-	x	5
C. Steel Tape		x	x	x-		5
F. Roller Chain		x	x	x-		5
G. Jointed Links		x	x	x-		5
A. Wire Rope		x	x+	x-		4

*x- = mildly; x = moderately; x+ = strongly

PROJECTED SYSTEM WEIGHT

Since all the proposed tension members are designed to have the same ultimate breaking strengths, the candidates may be evaluated by their relative weight and also by the expected relative weights of the entire hoisting mechanism. The hoist-system weight for the roller chain is expected to be high because of the full-gimbaling requirement for accommodation of the desired cone angle. Table XXV summarizes this evaluation of projected system weight.

TABLE XXV. SYSTEM WEIGHT EVALUATION

Concept	Relative Tension-Member Weight	Estimated Relative Hoist Weight	Evaluation
C. Steel Tape	1	1 (reel)	10
E. Synthetic Tape	1	2 (reel)	9
B. Wire-Rope Belt	2	2 (reel)	8
D. Synthetic Rope	1	3 (drum and level wind)	7
A. Wire Rope	2	3 (drum and level wind)	6
G. Jointed Links	3	6 (positive drive)	2
F. Roller Chain	12	4 (positive drive)	1

STATIC ELECTRICITY

The problem of dangerous static electricity discharge becomes a question of the relative conductivity of each tension-member concept. There is now no known effective way of reducing the static electricity buildup on the helicopter to a safe level, due in part to the difficulty in sensing the potential difference between the aircraft and ground. Therefore, a conductive tension member must be grounded before being handled during load acquisition; the grounding is required during the entire operation, as the static charge can build up rapidly. A nonconductive tension member acts as an insulator between the aircraft and ground, effectively preventing a dangerous static discharge which might injure ground personnel or damage cargo by igniting fuel vapor or explosives. The concepts are evaluated as shown in Table XXVI in direct proportion to their conductivity. Here it is assumed that the power conductors to the hook will not contribute to the static electricity problem (i.e., signals to the hook are transmitted by means other than electric wires).

TABLE XXVI. STATIC ELECTRICITY EVALUATION

Concept	Evaluation
D. Synthetic Rope	10
E. Synthetic Tape	10
B. Wire-Rope Belt	4
F. Roller Chain	3
G. Jointed Links	3
A. Wire Rope	2
C. Steel Tape	2

INSPECTION

The present method of inspecting a helicopter hoist cable (wire rope) is to extend the cable and visually observe for signs of broken wires. While this method is adequate for detecting external flaws, it neglects any internal damage which may have occurred. The inspection of a tension member, therefore, should be both for external and for internal damage. Electromagnetic NDT (nondestructive test) devices are now available and could be used for detecting broken wires in both the wire-rope and wire-rope-belt designs. Wire-rope belt, however, cannot be visually inspected for external broken wires.

Steel tape can be visually inspected for nicks and scratches. Several types of conventional NDT methods also are available to detect fatigue cracks. Synthetic tape is more easily inspected for external wear or chafing than synthetic rope because of its greater exposed surface area, but no effective means is now available for inspecting either for internal fiber breakage or embrittlement. The Government is, however, sponsoring a major program to develop an NDT system for slings. The same technique can be applied to the synthetic tapes.

Roller chain and jointed links are easy to visually inspect externally, but detection of internal damage and wear to rollers, pins, and universal joints would require complete disassembly. The evaluation shown in Table XXVII considers the ease with which each tension member may be inspected for the damage and wear which might reduce its strength or shorten its life.

TABLE XXVII. EVALUATION OF INSPECTION

Concept	Inspection: Internal	Inspection: External	Evaluation
C. Steel Tape	Not necessary	Visual/NDT	9
E. Synthetic Tape	NDT	Visual	8
A. Wire Rope	NDT	Visual	7
D. Synthetic Rope	Not possible	Visual	6
F. Roller Chain	Disassembly	Visual	6
G. Jointed Links	Disassembly	Visual	6
B. Wire-Rope Belt	NDT	Not possible	5

PROJECTED HOIST COMPLEXITY

The ease with which a tension member may be hoisted and stored within the aircraft is indicated by the complexity of the extend-and-retract mechanism. There are three basic systems under consideration for the proposed tension-member concepts. Flat-belt-type tension members, such as wire-rope belt, steel tape, and synthetic tape, will be hoisted by and stored in several layers upon a simple reel. Elastic deformations of the synthetic tape may require additional sophistication in the reel design to prevent lateral squeeze-out or jamming. Wire rope and synthetic rope will require a level-wind mechanism to apply a single layer of rope to the drum without adverse scuffing or damaging crossovers. Roller chain may be hoisted by gear-driven sprockets and stored in a bin. Jointed links might be hoisted by and stored upon a drum having a hexagonal or octagonal cross section. The more complex the mechanism, the more it is likely to cost, the more maintenance it will require, and the less likely it is to function properly.

The tension member must be allowed freedom to swing both in the fore-and-aft direction and also side-to-side. Because of this requirement, several of the proposed tension members need special features in the hoist system. Wire rope will need a large-radius bellmouth or a gimbaled sheave at the entrance to the hoist, as will synthetic rope. Wire rope belt, steel tape, and synthetic tape will require gimbaled fairlead rollers, some distance from the storage reel, to allow for side-to-side swinging of the load; in this case, the belt or tape will be required to twist to accommodate the motion of the gimbaled rollers. Steel tape will require a large distance between the reel and the gimbaled rollers to prevent excessive stresses in the edges of the tape as the tape twists due to lateral load swing. Roller chain would swing freely in the fore-and-aft direction, but its transverse stiffness would require gimbaling the entire hoist system. The jointed-link concept is the only tension member which would not require additional hardware to accommodate the desired cone angle.

The tension-member concepts are evaluated as illustrated in Table XXVIII for complexity of their necessary hoist, fairlead, and storage systems.

TABLE XXVIII. HOIST COMPLEXITY EVALUATION

Concept	Hoisting Method	Complexity	Evaluation
C. Steel Tape	Reel and gimbaled fairlead rollers	Moderate	8
B. Wire-Rope Belt	Reel and gimbaled fairlead rollers	Moderate	8
E. Synthetic Tape	Reel and gimbaled fairlead rollers	Moderate	7
A. Wire Rope	Drum with level wind and bellmouth or gimbaled sheave	High	6
D. Synthetic Rope	Drum with level wind and bellmouth or gimbaled sheave	High	5
F. Roller Chain	Positive drive (sprockets), bin storage, gimbaled winch	High	4
G. Jointed Links	Specially configured drum	High	3

PROJECTED SYSTEM SIZE

The evaluation for projected system size shown in Table XXIX is based on the minimum bend radius of the tension member; the smaller the minimum bend radius, the smaller the drum or reel size necessary, and the smaller the fairlead sheave or rollers. The minimum bend radius has been selected (based on available experimental data) to assure that the tension member will have an adequate fatigue life, and gives an indication of the effect of fatigue-life requirements on the size of the hoist system.

TABLE XXIX. SYSTEM SIZE EVALUATION

Concept		Load Case					
		30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
E. Synthetic Tape	MBR*	5.6	5.6	5.6	5.6	5.6	5.6
	EV**	9	9	9	9	9	9
F. Roller Chain	MBR	7	7	8.5	7	7	8.5
	EV	8	8	8	8	8	8
B. Wire-Rope Belt	MBR	8.3	9.8	11.3	6.8	8.3	9
	EV	8	7	7	8	8	8
D. Synthetic Rope	MBR	11	13	15	9.5	10.5	12
	EV	7	6	6	7	7	7
A. Wire Rope	MBR	16.5	19.5	21.8	14.3	16.5	18
	EV	5	4	4	6	5	5
C. Steel Tape	MBR	20	20	20	20	20	20
	EV	4	4	4	4	4	4
G. Jointed Links	MBR	24	24	24	24	24	24
	EV	3	3	3	3	3	3

* MBR = Minimum bend radius, inches.

** EV = Evaluation.

END CONNECTIONS REQUIRED

One of the important design problems for each tension member is the development of a fitting for both the hook end and the hoist end which will carry the maximum percentage of the tension-member strength. For instance, available end fittings for wire ropes can develop 100 percent of the rope ultimate tensile strength. End fittings on synthetic tape, however, can currently develop only about 80 percent of the tape's breaking strength. A part of this problem can be attributed to the difficulty of transferring the load from all elements of a wide flat shape to a central section such as a swivel for the pickup hook. Another consideration is the expected weight of the end fittings; for example, the common end fitting without swivel adaptor for a 2-inch wire rope weighs approximately 80 pounds.

The evaluation of the proposed tension-member concepts shown in Table XXX with regard to end fitting design compromise, includes the effects of tension-member shape, percentage of ultimate tensile strength developed, and estimated relative fitting weight.

TABLE XXX. EVALUATION OF END CONNECTIONS

Concept	Shape	Percent of UTS Developed	Relative Weight	Evaluation
A. Wire Rope	Round	100	1	9
G. Jointed Links	Round	100	1	9
D. Synthetic Rope	Round	95	1	8
B. Wire-Rope Belt	Flat	100	2	8
F. Roller Chain	Flat	100	2	8
C. Steel Tape	Flat	95	2	7
E. Synthetic Tape	Flat	80	2	6

ABRASION RESISTANCE

The abrasion resistance of a tension member is a measure of its ability to withstand the conditions likely to cause external wear. These conditions include dragging the tension member against rocks or other objects, and sliding contact with surfaces in the hoist system. Any tension member which may be successfully coated without detrimentally affecting its operation can be considered strongly abrasion resistant because wearing away of the coating in no way reduces its efficiency. On the other hand, wire rope cannot be considered as abrasion resistant because high contact pressures are likely to cause significant wear under severe conditions. In general, though, all concepts under consideration are sufficiently abrasion resistant that they can be made to perform satisfactorily in this application. This is illustrated by the evaluation in Table XXXI.

TABLE XXXI. EVALUATION OF ABRASION RESISTANCE

Concept	May be Coated	Evaluation
B. Wire-Rope Belt	x	9
E. Synthetic Tape	x	9
G. Jointed Links		9
C. Steel Tape	x	9
F. Roller Chain		9
D. Synthetic Rope	x	8
A. Wire Rope	x	7

SUSCEPTIBILITY TO GUNFIRE

The susceptibility of a tension member to gunfire can be judged by determining the tension-member vulnerability and the strength remaining in the member after a single hit by a 12mm projectile. The destructive energy in a bullet this size is sufficient to cause it to pierce and pass through any of the proposed tension members from any angle of penetration. The question of relative susceptibility to gunfire is a measure of the strength of the remaining material and the possibility of stress concentration. Another factor is the number of elements of the tension member that are detrimentally affected. A wire rope might lose several strands, but the load may be taken on the remaining strands. A flat steel tape, however, will suffer a stress concentration at the hole which could cause crack propagation and severing of the tension member. The evaluation for the tension-member susceptibility to gunfire considers these two aspects in the following manner. First, the approximate area loss due to a direct hit is computed and expressed as a percentage of the total area. For flat shapes, the angle of penetration for area loss calculations is assumed to be at 60° to the perpendicular to the flat side. An initial evaluation is then selected from Figure 24. This value is reduced by 2 for steel tape and jointed links to reflect the probability of stress concentration around the hole. Finally, the relative projected area, a measure of tension-member vulnerability, is computed using the maximum width for each tension member. To obtain a final evaluation value, 1 is added to the initial evaluation for tension members with relative projected areas from 1 to 3, no change is made for relative projected areas from 4 to 7, and 1 is subtracted from the initial values for tension members with relative projected areas from 8 to 10. The evaluation results follow in Table XXXII.

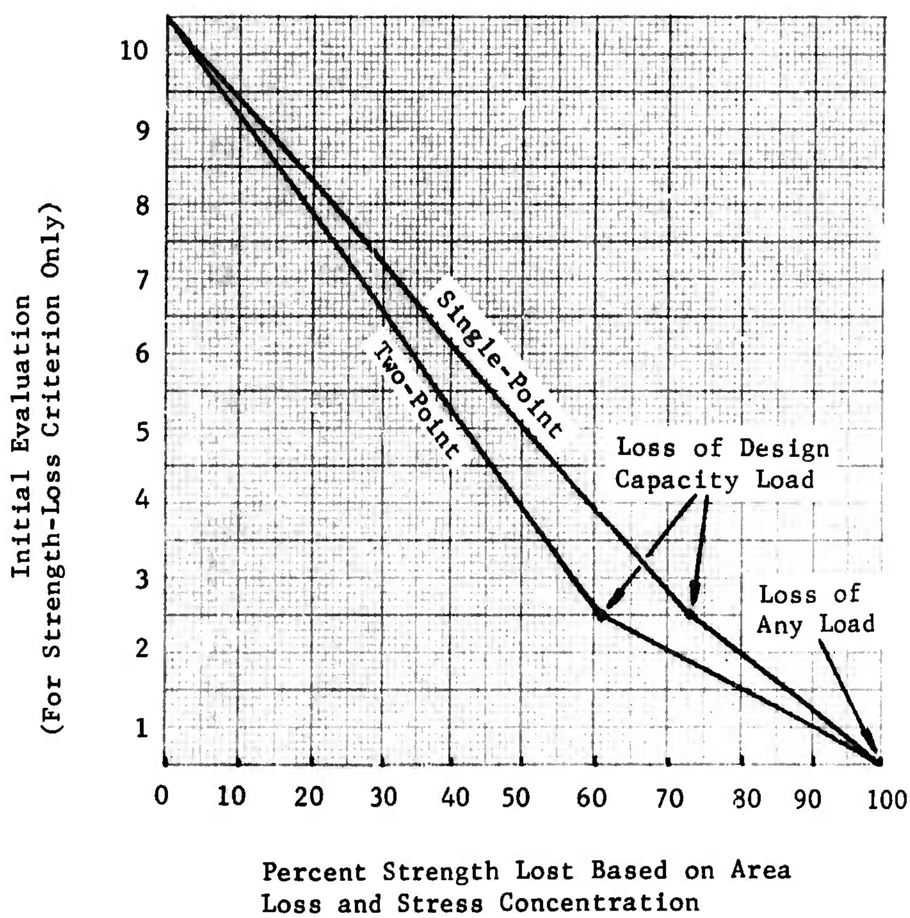

Figure 24. Effect of Direct Hit by 12MM Projectile.

TABLE XXXII. EVALUATION OF SUSCEPTIBILITY TO GUNFIRE

Concept		Load Case 30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
D. Synthetic Rope	PSL[a]	25	20	18	28	22	21
	RPA[b]	2	2	2	2	2	2
	EV[c]	9	9	10	8	9	9
E. Synthetic Tape	PSL	13	10	8	19	14	11
	RPA	6	6	7	5	5	6
	EV	9	9	10	8	9	9
F. Roller Chain	PSL	25	17	25	33	25	33
	RPA	6	9	6	6	7	6
	EV	8	8	8	6	7	6
B. Wire-Rope Belt	PSL	40	34	29	48	40	34
	RPA	2	2	2	2	2	2
	EV	7	8	8	5	6	7
A. Wire Rope	PSL	47	36	33	52	43	40
	RPA	1	1	1	1	1	1
	EV	6	8	8	5	6	6
C. Steel Tape	PSL	17	13	10	24	18	15
	RPA	4	5	5	3	4	5
	EV	7	7	7	6	6	7
G. Jointed Links	PSL	41	36	32	50	43	38
	RPA	1	1	1	1	1	1
	EV	5	6	6	3	4	5

(a) Percent strength loss.

(b) Relative projected area.

(c) Evaluation.

TORSIONAL CHARACTERISTICS

Two aspects of a tension member's torsional behavior must be considered. First, is the tension member naturally nonrotative? In other words, does the tension member have a tendency to "unwind" or rotate when a load is applied? "Nonrotating" wire-rope constructions have only a slight tendency to rotate under load, while roller chain, jointed links, synthetic rope and synthetic tape are completely nonrotative. Wire-rope belt also can be designed to be nonrotative. Therefore, use of swivels will not be necessary to prevent cargo rotation due to tension-member torque.

Another consideration is the ability of the tension member to accept turning of the load without undue torsional stresses. This is really a measure of torsional stiffness. This second aspect is not as important a consideration in a multipoint hoist configuration where the load naturally aligns with the aircraft, but will necessitate a swivel for all proposed tension members in the single-point hoist configuration. Both the antirotative behavior and the torsional stiffness, then, are considered in the evaluation in Table XXXIII.

TABLE XXXIII. EVALUATION OF TORSIONAL CHARACTERISTICS

Concept	Anti-rotation	Relative Torsional Stiffness	Swivel Necessary Single Point	Swivel Necessary Two Point	Evaluation Single Point	Evaluation Two Point
B. Wire-Rope Belt	Excellent	Low	Yes	No	10	10
E. Synthetic Tape	Excellent	Low	Yes	No	10	10
C. Steel Tape	Excellent	Low	Yes	No	10	10
D. Synthetic Rope	Excellent	Low	Yes	No	10	10
A. Wire Rope	Good	Low	Yes	No	8	8
F. Roller Chain	Excellent	Moderate	Yes	Yes	6	6
G. Jointed Links	Excellent	Moderate	Yes	Yes	6	6

RESISTANCE TO SHOCK UNLOADING

The resistance of a tension member to shock unloading may be defined as a measure of resistance to kinking or birdcaging upon quick release of the load. Sudden load release may be a result of either a severe negative vertical gust or loss of tension due to emergency or accidental release of cargo.

The tendency of a tension member to kink under these conditions is related to its antirotative characteristics. That is, if a large amount of energy is stored in the tension member due to torsional movement, this energy may cause a loop to form upon sudden load release and then kinking will occur when the slack is taken up. Kinking can cause severe damage to the tension member, necessitating replacement.

Another form of shock-unloading damage that applies to the wire-rope and wire-rope-belt tension members is birdcaging, a permanent localized "ballooning" or opening up of the wires and strands. This phenomenon is not uncommon in wire ropes when rope tension is suddenly released.

The evaluation shown in Table XXXIV reflects the tension-member susceptibility to damage from stored torsional energy (tendency to kink) and tendency to birdcage.

TABLE XXXIV. EVALUATION OF RESISTANCE TO SHOCK UNLOADING

Concept	Tendency to Kink	Tendency to Birdcage	Evaluation
C. Steel Tape	None	None	10
D. Synthetic Rope	None	None	10
E. Synthetic Tape	None	None	10
F. Roller Chain	None	None	10
G. Jointed Links	None	None	10
B. Wire-Rope Belt	None	Slight	8
A. Wire Rope	Moderate	Moderate	6

ACCEPTANCE OF POWER CONDUCTORS

Ideally, the conductors necessary to power and control the hook actuation would be an integral part of the tension member, while in no way degrading the tension member strength or performance. This situation, however, is not achievable in most cases. Wire rope can accept power conductors as a center core, but it then loses the strength of the center core strand. Wire-rope belt may be able to accept electrical conductors embedded in the spaces between the ropes, but this technique is untried. Power conductors must obviously be separate from a steel-tape tension member.

Synthetic rope could probably be made to accept an integral power conductor, but this requires the design of a conductor to accept the high elongation under load without breaking. (Synthetic rope has been made with a central electrical conductor, similar to wire rope, with the conductor preformed as a spiral to allow large elongations.)

Because of their configuration, both roller chain and jointed links must have a separate system for conducting power to the hook. When examined in the light of inspectability and safety, a separate reeling system for the power conductors may be desirable; conductors could then be easily examined for wear and damage, and faulty conductors could be replaced without removal of the tension member itself. The disadvantage of a separate system, besides the extra weight and complexity, is the possibility that the conductors may become entangled with the tension member, interfering with the normal modes of operation. This problem may be alleviated by providing some means of attaching the power conductors to the tension member.

An evaluation of each tension-member concept relative to these power-conductor considerations is shown in Table XXXV.

TABLE XXXV. EVALUATION OF ACCEPTANCE OF POWER CONDUCTORS

Concept	Integral Power Conductor	Compromise	Could a Separate Power Conductor Be Conveniently Attached to the Tension Member?	Evaluation
A. Wire Rope	Yes	Slightly lower strength	Yes	9
B. Wire-Rope Belt	Yes	None	Yes	9
F. Roller Chain	No	Separate reel	Probably	5
G. Jointed Links	No	Separate reel	Probably	5
C. Steel Tape	No	Separate reel	Possibly	4
D. Synthetic Rope	Possibly	Lower strength	Difficult	3
E. Synthetic Tape	No	Separate reel	Difficult	3

EASE OF HANDLING

Ease of handling is a measure of the difficulty that ground personnel might encounter in manipulating the tension member during load acquisition, as well as the difficulty expected when maintenance personnel attempt to install, inspect, or remove the tension member. Several factors might affect handling: tension-member flexibility, weight, and surface configuration. For example, one man would not be able to lift more than a few feet of roller chain, whereas he would have no difficulty in picking up long lengths of synthetic rope. Also, gloves might be necessary to avoid cuts and scrapes when handling steel tape, while synthetic tape would have no sharp edges. The evaluation is summarized in Table XXXVI.

TABLE XXXVI. EVALUATION OF EASE OF HANDLING

Concept	Flexibility	Relative Weight	Configuration	Evaluation
D. Synthetic Rope	Excellent	1	Round, smooth	10
E. Synthetic Tape	Excellent*	1	Flat, smooth	9
B. Wire-Rope Belt	Good*	2	Flat, smooth**	8
A. Wire Rope	Fair	2	Round, rough	6
C. Steel Tape	Fair*	1	Flat, sharp edges	5
G. Jointed Links	Excellent	3	Round, varying section	4
F. Roller Chain	Excellent*	12	Flat, rough, sharp edges	2

*Directional.

**Coated.

MAINTENANCE

Maintenance considerations include both the amount of maintenance likely to be required to keep the tension member in operating condition and also the degree of difficulty of that maintenance. Wire rope will require little or no maintenance beyond an occasional cleaning and possibly periodic lubrication. Wire-rope belt with its fully encapsulated form should require no maintenance. Steel tape, unless coated, will require removal of (or protection from) corrosion as it occurs. Both synthetic rope and synthetic tape are considered maintenance-free. Roller chain would probably require the most attention; constant lubrication would be a necessity, and would require cleaning of sand and grit from the surface. Damaged links or rollers would require replacement. Jointed links would need frequent lubrication of the universal joints, as well as joint renewal prior to failure. The evaluation in Table XXXVII considers both the need for maintenance and the difficulty of performing the required maintenance.

TABLE XXXVII. MAINTENANCE EVALUATION

Concept	Need for Maintenance	Degree of Difficulty	Evaluation
B. Wire-Rope Belt	None	-	10
D. Synthetic Rope	None	-	10
E. Synthetic Tape	None	-	10
A. Wire Rope	Low	Low	8
C. Steel Tape	Moderate	Moderate	6
G. Jointed Links	High	Moderate	4
F. Roller Chain	High	High	3

APPENDIX III

PARAMETRIC EVALUATION OF CANDIDATE TENSION-MEMBER CONCEPTS

TABLE XXXVIII. WIRE-ROPE TENSION-MEMBER EVALUATION BY PARAMETER

	Combined Category/ Parameter Weight	Assigned Values for Six Load Cases					
		30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Ease of Guillotining	10	8	8	8	8	8	8
Stored Energy - Elasticity	10	7	7	7	7	7	7
Aerodynamic Considerations	8	9	9	9	9	9	9
Resistance to Shock Loading	7	3	3	3	3	3	3
Resistance to Thermal Damage	7	8	8	8	8	8	8
Resistance to Environmental Damage	7	4	4	4	4	4	4
Projected System Weight	7	6	6	6	6	6	6
Static Electricity	5	2	2	2	2	2	2
Inspection	5	7	7	7	7	7	7
Projected Hoist Complexity	5	6	6	6	6	6	6
Projected System Size	5	5	4	4	6	5	5
End Connections Required	4	9	9	9	9	9	9
Abrasion Resistance	3	7	7	7	7	7	7
Susceptibility to Gunfire	3	6	8	8	5	6	6
Torsional Characteristics	3	8	8	8	8	8	8
Resistance to Shock Unloading	3	6	6	6	6	6	6
Acceptance of Power Conductors	3	9	9	9	9	9	9
Ease of Handling	2	6	6	6	6	6	6
Maintenance	1	8	8	8	8	8	8

TABLE XXXIX. WIRE-ROPE-BELT TENSION-MEMBER EVALUATION BY PARAMETER

	Combined Category/ Parameter Weight	Assigned Values for Six Load Cases					
		30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Ease of Guillotining	10	6	6	6	6	6	6
Stored Energy - Elasticity	10	7	7	7	7	7	7
Aerodynamic Considerations	8	7	7	7	7	7	7
Resistance to Shock Loading	7	3	3	3	3	3	3
Resistance to Thermal Damage	7	9	9	9	9	9	9
Resistance to Environmental Damage	7	9	9	9	9	9	9
Projected System Weight	7	8	8	8	8	8	8
Static Electricity	5	4	4	4	4	4	4
Inspection	5	5	5	5	5	5	5
Projected Hoist Complexity	5	8	8	8	8	8	8
Projected System Size	5	8	7	7	8	8	8
End Connections Required	4	8	8	8	8	8	8
Abrasion Resistance	3	9	9	9	9	9	9
Susceptibility to Gunfire	3	7	8	8	5	6	7
Torsional Characteristics	3	10	10	10	10	10	10
Resistance to Shock Unloading	3	8	8	8	8	8	8
Acceptance of Power Conductors	3	9	9	9	9	9	9
Ease of Handling	2	8	8	8	8	8	8
Maintenance	1	10	10	10	10	10	10

TABLE XXXX. STEEL-TAPE TENSION-MEMBER EVALUATION BY PARAMETER

	Combined Category/ Parameter Weight	Assigned Values for Six Load Cases					
		30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Ease of Guillotining	10	9	9	9	9	9	9
Stored Energy - Elasticity	10	9	8	8	8	8	8
Aerodynamic Considerations	8	4	4	4	4	4	4
Resistance to Shock Loading	7	2	2	2	2	2	2
Resistance to Thermal Damage	7	10	10	10	10	10	10
Resistance to Environmental Damage	7	5	5	5	5	5	5
Projected System Weight	7	10	10	10	10	10	10
Static Electricity	5	2	2	2	2	2	2
Inspection	5	9	9	9	9	9	9
Projected Hoist Complexity	5	8	8	8	8	8	8
Projected System Size	5	4	4	4	4	4	4
End Connections Required	4	7	7	7	7	7	7
Abrasion Resistance	3	9	9	9	9	9	9
Susceptibility to Gunfire	3	7	7	7	6	6	7
Torsional Characteristics	3	10	10	10	10	10	10
Resistance to Shock Unloading	3	10	10	10	10	10	10
Acceptance of Power Conductors	3	4	4	4	4	4	4
Ease of Handling	2	5	5	5	5	5	5
Maintenance	1	6	6	6	6	6	6

TABLE XXXXI. SYNTHETIC-ROPE TENSION-MEMBER EVALUATION BY PARAMETER

	Combined Category/ Parameter Weight	Assigned Values for Six Load Cases					
		30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Ease of Guillotining	10	10	10	10	10	10	10
Stored Energy - Elasticity	10	1	1	1	1	1	1
Aerodynamic Considerations	8	8	8	8	8	8	8
Resistance to Shock Loading	7	10	10	10	10	10	10
Resistance to Thermal Damage	7	4	4	4	4	4	4
Resistance to Environmental Damage	7	5	5	5	5	5	5
Projected System Weight	7	7	7	7	7	7	7
Static Electricity	5	10	10	10	10	10	10
Inspection	5	6	6	6	6	6	6
Projected Hoist Complexity	5	5	5	5	5	5	5
Projected System Size	5	7	6	6	7	7	7
End Connections Required	4	8	8	8	8	8	8
Abrasion Resistance	3	8	8	8	8	8	8
Susceptibility to Gunfire	3	9	9	10	8	9	9
Torsional Characteristics	3	10	10	10	10	10	10
Resistance to Shock Unloading	3	10	10	10	10	10	10
Acceptance of Power Conductors	3	3	3	3	3	3	3
Ease of Handling	2	10	10	10	10	10	10
Maintenance	1	10	10	10	10	10	10

TABLE XXXXII. SYNTHETIC-TAPE TENSION-MEMBER EVALUATION BY PARAMETER

	Combined Category/ Parameter Weight	Assigned Values for Six Load Cases					
		30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Ease of Guillotining	10	10	10	10	10	10	10
Stored Energy - Elasticity	10	3	3	3	3	3	3
Aerodynamic Considerations	8	5	5	5	5	5	5
Resistance to Shock Loading	7	10	10	10	10	10	10
Resistance to Thermal Damage	7	6	6	6	6	6	6
Resistance to Environmental Damage	7	7	7	7	7	7	7
Projected System Weight	7	9	9	9	9	9	9
Static Electricity	5	10	10	10	10	10	10
Inspection	5	8	8	8	8	8	8
Projected Hoist Complexity	5	7	7	7	7	7	7
Projected System Size	5	9	9	9	9	9	9
End Connections Required	4	6	6	6	6	6	6
Abrasion Resistance	3	9	9	9	9	9	9
Susceptibility to Gunfire	3	9	9	10	8	9	9
Torsional Characteristics	3	10	10	10	10	10	10
Resistance to Shock Unloading	3	10	10	10	10	10	10
Acceptance of Power Conductors	3	3	3	3	3	3	3
Ease of Handling	2	9	9	9	9	9	9
Maintenance	1	10	10	10	10	10	10

TABLE XXXXIII. ROLLER-CHAIN TENSION-MEMBER EVALUATION BY PARAMETER

	Combined Category/ Parameter Weight	Assigned Values for Six Load Cases					
		30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Ease of Guillotining	10	3	3	3	3	3	3
Stored Energy - Elasticity	10	10	10	10	10	10	10
Aerodynamic Considerations	8	7	7	7	7	7	7
Resistance to Shock Loading	7	1	1	1	1	1	1
Resistance to Thermal Damage	7	10	10	10	10	10	10
Resistance to Environmental Damage	7	5	5	5	5	5	5
Projected System Weight	7	1	1	1	1	1	1
Static Electricity	5	3	3	3	3	3	3
Inspection	5	6	6	6	6	6	6
Projected Hoist Complexity	5	4	4	4	4	4	4
Projected System Size	5	8	8	8	8	8	8
End Connections Required	4	8	8	8	8	8	8
Abrasion Resistance	3	9	9	9	9	9	9
Susceptibility to Gunfire	3	8	8	8	6	7	6
Torsional Characteristics	3	6	6	6	6	6	6
Resistance to Shock Unloading	3	10	10	10	10	10	10
Acceptance of Power Conductors	3	5	5	5	5	5	5
Ease of Handling	2	2	2	2	2	2	2
Maintenance	1	3	3	3	3	3	3

TABLE XXXXIV. JOINTED-LINK TENSION-MEMBER EVALUATION BY PARAMETER

	Combined Category/ Parameter Weight	Assigned Values for Six Load Cases					
		30T-1	40T-1	50T-1	30T-2	40T-2	50T-2
Ease of Guillotining	10	4	4	4	4	4	4
Stored Energy - Elasticity	10	10	10	10	10	10	10
Aerodynamic Considerations	8	9	9	9	9	9	9
Resistance to Shock Loading	7	2	2	2	2	2	2
Resistance to Thermal Damage	7	10	10	10	10	10	10
Resistance to Environmental Damage	7	5	5	5	5	5	5
Projected System Weight	7	2	2	2	2	2	2
Static Electricity	5	3	3	3	3	3	3
Inspection	5	6	6	6	6	6	6
Projected Hoist Complexity	5	3	3	3	3	3	3
Projected System Size	5	3	3	3	3	3	3
End Connections Required	4	9	9	9	9	9	9
Abrasion Resistance	3	9	9	9	9	9	9
Susceptibility to Gunfire	3	5	6	6	3	4	5
Torsional Characteristics	3	6	6	6	6	6	6
Resistance to Shock Unloading	3	10	10	10	10	10	10
Acceptance of Power Conductors	3	5	5	5	5	5	5
Ease of Handling	2	4	4	4	4	4	4
Maintenance	1	4	4	4	4	4	4